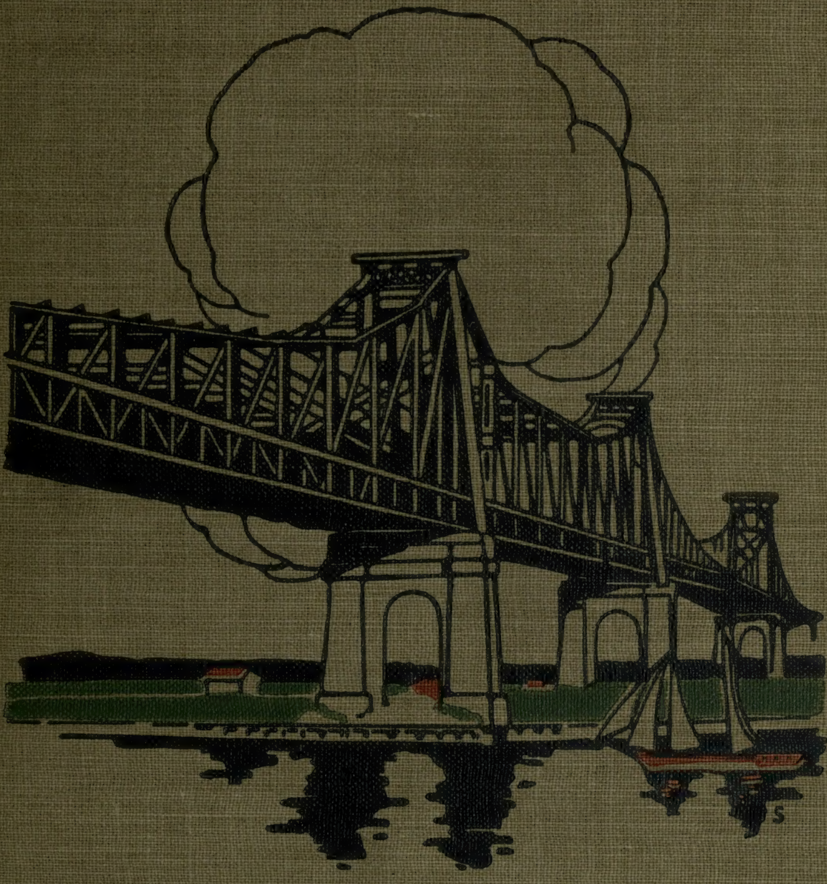
On the BATTLE FRONT of ENGINEERING



A. RUSSELL BOND

From Mother
Christmas
1916

ON THE BATTLE-FRONT
OF ENGINEERING

HE WAS THE LAST ONE TO COME THROUGH.

ON THE BATTLE FRONT OF ENGINEERING

BY

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WITH MANY
ILLUSTRATIONS

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PREFACE

This is a book of war. It deals with a form of warfare in which America excels. The struggles of our engineers against overwhelming forces of nature, their daring ventures, and magnificent achievements, are as full of live interest as any story of battle between man and man.

The author has endeavored to set down some of the more unusual exploits of American engineers in such a way as to appeal to a boy and to satisfy his natural craving for adventure, while, at the same time, teaching him some of the elements of civil engineering. This has called for a combination of fact and fiction. However, all the adventures recounted are actually based on fact, although they have been altered and modified to fit the special requirements of the narrative. But no liberties have been taken with engineering data. Realizing the importance of imparting correct information, many engineers have been consulted and they have been most helpful in offering sugges-

tions, in furnishing material, in recounting their personal experiences, and in carefully revising the manuscript. Nearly every chapter has been read and corrected by an engineer who was directly concerned with the work therein described. The author is glad of this opportunity to acknowledge his indebtedness.

Mr. Edwin S. Jarett and his associate, Mr. R. H. Chambers, have given invaluable assistance in connection with Chapters I, VI, VII, and XIII. Photographs for Chapters I, VIII, and XIII were very kindly loaned by The Foundation Company, and Mr. H. J. Deutschbein of that company was good enough to revise some of the manuscript. Photographs illustrating Chapter VI were loaned by the Electric Bond and Share Company and Mr. A. C. Clohger of that company very kindly read and corrected the manuscript. Thanks are due to Mr. Fred L. Cranford for assistance in preparing Chapter II; to Mr. Bert A. Heinly for illustrations and data used in Chapter III; and to Mr. Hugh L. Cooper for the adventure recounted in Chapter IV. The photographs illustrating this chapter were supplied by the Lidgerwood Manufacturing Company and Mr. J. Sinclair of that company furnished valuable assistance. Mr. L. E. Palmer and the Stone

and Webster Engineering Corporation, with which he is associated, were most helpful in loaning photographs and furnishing data on the Big Creek development (Chapter V). The Monighan Machine Company loaned the illustrations of the walking dredge (Chapter IX) and C. J. Carpenter, of the Carpenter Construction Company, supplied the picture of the giant tunnel auger (Chapter X). Mr. G. H. Duggan, Chief Engineer of the St. Lawrence Bridge Company, contributed the photographs and material for the article on the Quebec Bridge, and the manuscript was revised by Mr. Frank W. Skinner. Mr. George B. Frey showed the author the work described in Chapter XII, and Mr. Charles W. Staniford, Chief Engineer of the Department of Docks, New York, supplied much valuable material and very kindly examined the manuscript of the chapter on the thousand-foot piers. For the matter relating to boiler explosions and the story at the end of Chapter XIII the author is indebted to Mr. William H. Boehm, Vice-President of the Fidelity and Casualty Company of New York. Chapters XV to XVIII are based on articles appearing in *The Engineering Press* prepared by Mr. Harold Carpenter, Resident Engineer of the Astoria Gas Tunnel. With the

permission of the Consolidated Gas Company, Mr. Carpenter conducted the author through the tunnel. For the photographs and material on New York's subways, a heavy debt is owed to Mr. Robert Ridgeway, Engineer of Subways, of the Public Service Commission of the First District of New York, and to many of the division engineers. Mr. Clifford Holland was particularly helpful in supplying material for the last three chapters of the book. The author also wishes to acknowledge his indebtedness to Mr. John F. O'Rourke for data used in the chapters on the tunnels under the East River and to Mr. George P. Perrine for the work on "The Honeycomb" in Chapter XIV.

A. Russell Bond.

New York,
July, 1916.

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CHAPTER I

HARNESSING THUNDER RIVER

AS the harrow reached the corner of the wheatfield at the very brink of Eagle Bluff, Jack drew rein and paused to gaze down the canyon. The view was glorious; but he was not taking in the scenery just then. It was no new sight to him.

Five hundred feet below him, Thunder River wound its way through the gorge. More than half-way across the river stretched the massive foundations of a concrete dam, while about them the waters fretted and fussed, plainly displaying their irritation at this invasion of their domain. Above and below the concrete work were two temporary dams which had been designed to divert the river and compel it to flow around the site of the foundation work, through an enor-

mously large wooden flume. But the last spring flood had torn a big section out of each of these diversion dams, and through them the water now flowed almost without obstruction. Since that flood Jack had been unable to detect any progress in the building of the dam. Apparently the work had stopped. But now for the first time in many weeks he noticed considerable human activity down there.

"Looks as if they meant to start work again" (Jack had a way of thinking aloud), "but, jiminy! they can't get ahead of old Thunder River. She 's not going to let any one bottle her up. No siree!"

The young farmer picked up the reins and was about to chirrup to his horses when he noticed a boy of about his own age picking his way along the trail that zigzagged up the face of the bluff. Jack waited for the stranger to come up.

"Quite a stiff climb, is n't it?" he volunteered. "Snake Trail is pretty steep."

"It certainly is," agreed the newcomer, dropping down on a rock and mopping his forehead with a handkerchief. "But, I say! it 's worth it. What a wonderful view!"

"Do you come from the camp down there?" ventured Jack.

"Yes, my name is Carpenter—Perry Carpen-

ter. I don't know much about engineering, but my father sent me out here for my health. And your name?"

"Oh, I 'm Jack Winans."

"By George!" exclaimed Perry, "that river looks as calm as a mill-pond. It seems as if you could almost jump across the gap in the dam."

"But it 's a mighty hard matter to close that gap," declared Jack. "I don't believe Thunder River ever can be dammed."

"Why not?" demanded Perry.

"Have n't they been trying to do it for years? They thought they had her broken into the harness once; and they had, too, for a while. They built a big steel dam—"

"A steel dam!" interrupted Perry. "Why, I never heard of building a dam of steel!"

"Yes; it was steel. Did n't you folks have to haul out a pile of steel junk?"

"Maybe the other contractors did," said Perry. "We 've only just arrived. Came last night."

"What, a new contractor?" exclaimed Jack. "And the others have given up, have they?"

"Well, no; not exactly. They have just called us in to help them with the foundations at the west end of the dam."

"Well, you 'll never succeed," declared Jack.

"Won't we?" answered Perry. "Wait and see!"

"Yes; that 's it. Just wait," returned Jack. "You may get the foundations down and they may stay for a while; but just wait, and some day the water will creep under and wash them out. That 's the way it was with the first dam. It was a wonderful piece of work. I walked through it the day it was finished."

"Through it!"

"Yes. It was a hollow dam, you know. Just big triangles of steel set up on edge, 'bents' they called them, with sheets of steel stretched between them. Then at the up-stream side of the dam, to keep the water from getting under, they drove long, narrow plates of steel endwise into the ground, and each plate had a bead on one edge to fit into a groove in the edge of the next plate."

"Yes," nodded Perry, "I know—interlocking steel sheet-piles."

"Well, they drove those sheet-piles all along the up-stream edge of the dam down to rock, and I thought the river was mastered. Then one day, about a year later, I looked down off this bluff and old Thunder River had broken loose. She was racing through a break in that dam and just crumpling up that steel and push-

ing it aside like paper. They say the water got under the sheet-piling.''

''Of course,'' said Perry, ''how could they make a tight joint with the rock? And besides how did they know they had reached solid rock? They might have struck boulders. What they should have done was to dig right down to the rock, uncover it, and build a concrete wall right on it. Then the water could never get under.''

''Yes, that's all right,'' returned Jack; ''but it is easier said than done. Here these contractors have been trying to do it for two years. Look at that big flume there; a quarter of a mile long; the biggest flume I ever saw; fifty feet wide and fifteen feet deep! It took them a long time to build that flume, and then they built those two dams, you see, that have been broken through, and expected the whole river to flow around their works while they pumped out the water between the dams and laid their foundation on dry rock. Well, that looked good, too, except that they could n't pump the works out dry; and then the flume kept breaking, and last April, when the floods came, they swept right through those dams.''

''But we have a very different scheme,'' explained Perry. ''We are going to uncover that rock with the help of air.''

"Air!" exclaimed Jack.

"Yes; with pneumatic caissons. Ever hear of them?"

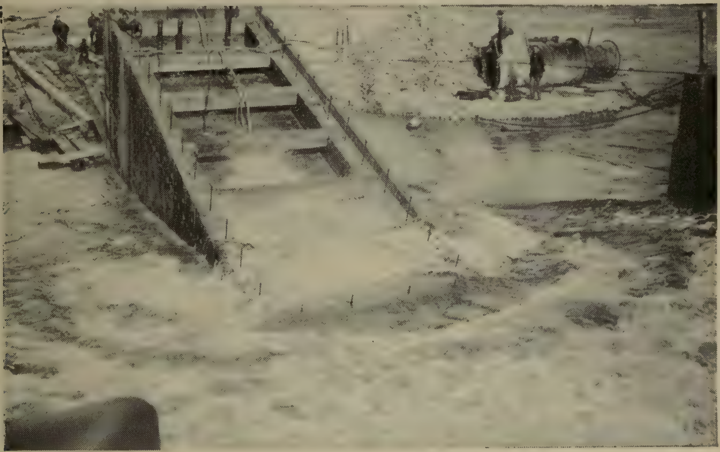
Jack shook his head.

"Well," continued Perry, "a caisson is a big box with steel cutting edges all around the bottom. The bottom of the box is open, but there is a partition wall across it about eight or ten feet up that forms the roof of a working-chamber. Workmen get into that chamber through a pipe, or shafting, that runs down from the top. Of course the sides of the box are built high enough to stick out above water-level. Then the men do down to the working-chamber, through the shafting."

"What, with the bottom of the box open?"

"Why, yes. They pump air in it to push the water down and keep it from rising up in the chamber. And I forgot to say there is an air lock at the top of the shafting, that is, a trap with two doors. When they go into the air lock from outside, the top door is open and the lower one closed. Then they close the upper door, and let in compressed air until the pressure in the lock is the same as that in the working-chamber. After which the bottom door opens and they can go on down the shafting. In the working-chamber the men keep digging

FIVE HUNDRED FEET BELOW HIM, THUNDER RIVER WOUND ITS WAY THROUGH THE GORGE.



WITH A MIGHTY LUNGE THE CAISSON SPLASHED INTO THE WATER.

out the earth and rock from under the caisson and let it settle deeper and deeper into the ground until they work their way down to solid rock. At the same time the caisson above the working-chamber is filled with concrete; and, after solid rock is reached, the working-chamber and shafting as well are filled with concrete. We are going to sink a ring of caissons all around the gap in the main dam, and in that way build a solid concrete cofferdam down to the rock. Then we can pump out the water in the cofferdam and dig out the earth, after which we can build our foundation right on the solid rock."

"That sounds all right," said Jack, "but how are you going to keep the creek from sweeping away your caissons while you are putting them down?"

"Just you leave that to Mr. Barto; he is a wonderful engineer."

"Well, I hope he does succeed. I 'm tired of this everlasting harrowing."

"What has that to do with it?" queried Perry.

"Why, when the dam is done and the power-plant is finished," explained Jack, "they are going to use part of the electricity to pump water out of the river and irrigate all these lands

around here. Then we 'll have no more bother with dry farming."

"Dry farming!" exclaimed Perry. "What do you mean by that?"

Jack's eyes opened in surprise. "Don't you know what dry farming is? Are all the farms irrigated where you come from?"

"Oh, in the East we have plenty of rain," declared Perry; "tell me what you do here."

"Well," explained Jack, "first we plow very deep, and break up the soil so that there are no lumps in it. Then we roll it down; that makes it hold water like a sponge. After that we harrow the top of the ground, to make a cover of loose earth over this sponge. The water does not soak up through this cover, because the earth is too loose. That keeps the sun from drying up the sponge. You know how wet the ground keeps under a board or a stone, because it can't dry out. It is just like that under the cover of loose soil. We can't afford to let the cover get hard or lumpy, because then the sponge down below will dry out, and so after every rain we have to go out and break up the clods and powder the soil. There was a professor out here last week, and he told me how the first fellow that learned to farm this way had noticed that where there had been hoof

prints and wheel tracks on his land the wheat grew better; and he figured out that the wheels squeezed the soil so that it made a better sponge to hold water, and the loose soil that was picked up by the wheel or the hoof and let fall on the track made a cover that kept the sun off the water and the water from working up to the top. But say, I must go on with my harrowing or old Billups will be after me."

"Who is that? Some relative?"

"Oh, no, I have n't any folks of my own. They farmed me out to this man Billups from the State Orphan-asylum for my board and keep. And he is n't losing a cent by the deal, I can tell you. By George, there he is now!" cried Jack, jerking the reins and chirruping to his horses.

"Come down and see me some time, Jack!" Perry cried after him. "I 'll take you down into a caisson and show you what it is like."

Many weeks passed before Jack availed himself of this invitation—Farmer Billups held his nose too close to the grindstone to let him get away even for an hour, and one could scarcely make the trip down the steep trail to the site of the dam and back again in much less time than that; but he often stole a chance to peer down from Eagle Bluff upon the busy workmen below. He watched them build a jetty from the up-

stream diversion dam to the finished part of the foundations of the main dam, so as to keep the water from flowing against their work. They

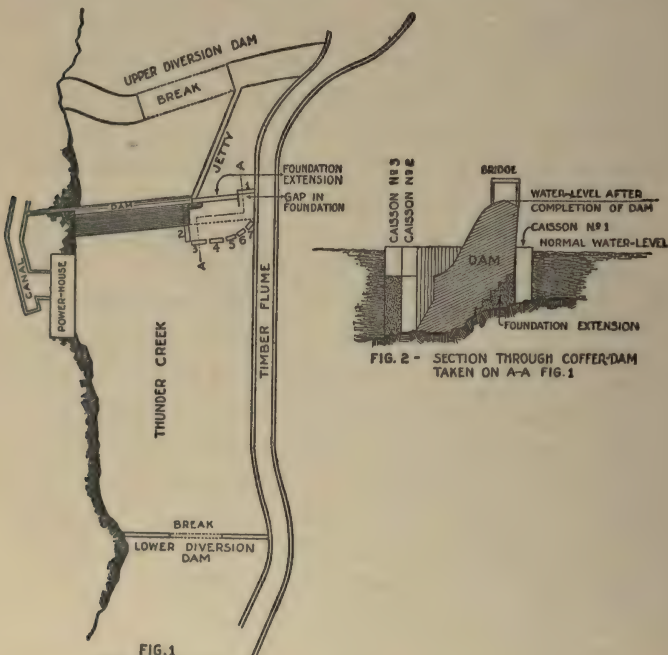


FIG. 2 - SECTION THROUGH COFFER-DAM TAKEN ON A-A FIG. 1

FIG. 1
PLAN VIEW OF DAM

seemed to be driving two rows of piles and then dumping rock between them. He saw them tow a great box, which he took to be a caisson, and sink it across the gap in the foundations. It was all very interesting.

Then one day came his chance. Farmer Billups went to town, and Aunt Judy, his wife, who had a tender place in her heart for the orphan, let Jack take the morning off to pay a visit to the dam.

There were twelve hundred men in that camp, but out of all that host one of the first to espy him was his friend Perry.

"Oh, hello, Jack!" he cried. "Say, you are just in time. They are going to launch caisson number four this morning. Come along, and we 'll see her take the water."

They hurried down to the shore of the creek, where a huge box of massive timbers rested upon an inclined launching-way. The two boys climbed in under the timbers on which the caisson was supported and stood up in the working chamber. Perry showed Jack the tapered cutting edges of the chamber, also the hole in the ceiling—or "deck," as he called it—of the working chamber, in which the shafting was going to be fitted.

"Hey, you young rascals, get out of there!" shouted the foreman of the job. "Do you want to be sliced in two? Can't you see we 're going to launch her?"

The boys scrambled out in haste. Some of the men were lowering the ways by means of

jacks. Soon the caisson trembled a bit as if dreading the plunge, then it began to move slowly down the ways, gathering speed as it went, until with a mighty lunge it splashed into the water and floated out upon the river with all the dignity of a stately ship. But a stout hawser brought it up with a jerk and ended its short cruise.

That was a wonderful morning for Jack. Perry took him all over the work and explained everything to the best of his knowledge. Jack was even introduced to the chief engineer, and felt very much flattered, although Mr. Barto had no time to talk to him.

The drawings, Figures 1 and 2, show how the work was to be done. The main contractors had already built the foundations across more than half of the stream and were now building the upper part of the dam. They had even extended a slice of the foundation on the up-stream side nearly all the way across. There was a gap of only thirty feet between the end of this slice and the west bank of the river. This gap had now been stopped by a caisson which was gradually burrowing down to solid rock. The plan was to sink six other caissons on the down-stream side of the work, as shown in Figure 1.

"What I can't make out," declared Jack, "is

how you are going to connect one caisson to another so that the water can't get through."

"That 's simple," explained Perry; "big twelve by twelve timbers will be fastened at the corners of each caisson. When the caissons are down all the way, a man will put planks across from one caisson to the other, nailing them to those corner timbers. That will make a little square shaft between the caissons. The top of the shaft will be sealed, with an air-lock in it so that the man can get inside, and then air pressure will be put on to keep the water down while he digs out between the caissons and keeps nailing on planks as he goes down. When he gets to the bottom, he will fill up the shaft with concrete and seal the caissons together."

"But then you 're going to leave a lot of timber down there between the concrete. Won't it rot out and break up your wall?"

"Do you know," said Perry, "that 's the very question I asked Mr. Barto. He says that wood does not rot under water and the timbers will be just as sound a hundred years from now as they are to-day. Come on over and let 's take a look at caisson number one."

"Are we going inside?" questioned Jack, eagerly.

"Sorry, Jack, but it can't be done!" answered

Perry. "Two of our men died of the caisson disease the other day. They were not regular sand-hogs, as the caisson workers are called, but men we picked up around here. They looked perfectly strong, and we could n't see what was the matter. But Dr. Crosby, who came up from town, says that you people who live out here in this high and dry climate have hardening of the arteries or something, and when the air pressure forces the blood in from the surface, it puts the arteries under a bigger strain than they can stand. Anyway he said we must n't let any more people from these mountains go into a caisson. So we had to telegraph East for more sand-hogs."

Jack was bitterly disappointed. He felt sure that he could stand the air pressure; but rules are rules, and he had to content himself with an exterior view. However, he asked so many questions that before he left, he knew almost as much about an air-lock and a caisson as if he had actually been inside.

The morning was so full of interest that Jack could scarcely believe it was noon when the whistle blew and reminded him it was time to go home. It was long before he had another chance to look at the work, although he saw Perry rather frequently. Perry often climbed up

Snake Trail to the top of Eagle Bluff to gaze through his field-glasses at the wonderful panorama, and, when he chanced to meet him, have a chat with Jack and tell him all the latest developments.

Work at Thunder Creek dam had progressed rapidly. The entire site of the foundations had been surrounded. The greatest difficulty had been to make a joint between the foundation already completed and caisson No. 2. By referring to Figure 2, which is a cross-section of the dam, it will be seen that the down-stream face of the dam was formed with what is known as an ogee curve and then slanted forward at a sharp angle which made the toe extend well in advance of the crest of the dam. Piles, made of squared timber, were driven in two rows through the material that had drifted over the toe. Strips of wood were nailed to the piles to form tongues and grooves which would lock one pile to the other. The piles were cut at the bottom to fit the contour of the dam. The material between the rows was dredged out, and divers closed up any gaps between the dam and the bottom of the piles.

But now all work had stopped, for it was Christmas Day; and when Jack came slipping and sliding down Snake Trail to make his first

visit in weeks, he found the camp deserted. Nearly every one, including Perry, had gone to town. The chief engineer, Mr. Barto, however, was on hand inspecting the work. Jack hung around, longing to have a talk with him, but rather shy about addressing him.

Mr. Barto was a man who never forgot a face. "Hello, Jack!" he cried, as he noticed the boy hanging around. "What do you think of it? We are getting along pretty well, are n't we? We ought to be pumping out the coffer-dam pretty soon. All our caissons are down, and most of the joints between them are finished. To-morrow, we 'll start filling with concrete the space between the two walls of piling."

"But it 's full of water, is n't it?" asked Jack. "You 'll have to pump that out, won't you?"

"No, we 'll deposit the concrete right through the water. The only drawback to concrete's setting under water is that the cement may be washed away; but there is no current there, and no reason why it should n't set perfectly, if we lower it carefully to the bottom and deposit it with self-dumping buckets."

"Do you know," ventured Jack, "I 've been trying to figure out what you 're going to do with your concrete wall after the dam is finished. Are you going to take it up?"

"Why should we?" answered Mr. Barto. "We have carried the concrete up only as far as the natural bed of the river. Above that we depend upon the timber caissons to keep out the water. After our work is done, we 'll take away the timber that projects above the river bed, and the pit between the dam and that wall will soon fill up with sand and bury all trace of the cofferdam.

"I'll have to go into number seven now. We 've had some trouble there. The rock is very poor, and we have had to excavate a deep hole below the caisson to get down to firm material."

As the two walked over to the lock, they came upon a man sunning himself in a nook where the icy winds could not reach him.

"Merry Christmas, Jimmy Doyle!" cried Mr. Barto, clapping the fellow on the shoulder. "Fine day, is n't it?"

"Merry Chrishmash," came the thick reply, "day 'zh all righ', so 'sh thish," taking a whiskey-flask out of his hip-pocket.

Mr. Barto seized the bottle and tossed it into the river. "Jim," he said, "you know that no liquor is allowed in camp!"

"But thish izh Chrishmash. Can't we have a merry Chrishmash?"

"Christmas or no Christmas," returned Mr. Barto, sternly, "nothing but water in this camp. Do you hear? Get back to your shack now. You 're in no condition to stay out in the cold."

Mr. Barto strode on to the caisson, climbed down into the air-lock and disappeared from view.

Because of the big pit that had been dug under the caisson, Mr. Barto had to take to a rope-ladder after reaching the bottom of the shafting. Very carefully he went over the surface of the rock, tapping it frequently to see if it was solid.

"It 's just a pocket," he muttered to himself; "I guess we can start concreting to-morrow."

As Mr. Barto was climbing out of one of the holes in the rock to reach the rope-ladder, he stepped on a rolling stone and fell heavily. His foot doubled up under him. Something snapped, and he felt a sharp stab in his ankle. Was the bone broken? At best it was a very severe sprain. The pain was excruciating. He was in a pretty fix, indeed. How could he ever climb up to the air-lock, particularly up the rope-ladder? For fully five minutes he lay there, wondering what he should do; then, with the utmost difficulty, he dragged himself up to within reach of the signal-rope and pulled it. Maybe some one would hear the signal. Maybe Doyle

JACK SENT HIM SPRAWLING OVER THE SIDE OF THE CAISSON, INTO THE ICY RIVER.

was sober enough to come to his assistance. Again he signaled, but there was no response. Then he heard the hiss of air.

"They 're coming to help me," he muttered. "Some one is coming through the air-lock."

But the sound of rushing air kept right on and no help appeared. Presently a tiny stream of water trickled out under the cutting edge of the caisson and splashed down upon him. From the opposite side another little stream came running in. Mr. Barto gazed dully at the water for a minute, then he gave an exclamation of horror.

"There 's a leak in the air-line somewhere!"

When Mr. Barto disappeared into the air-lock, Jack hung around uncertainly for a time. He did n't like the look of Jim Doyle when the chief engineer had taken away his liquor.

"I believe he means mischief," Jack muttered to himself. But Jim Doyle only stared at the hissing air-lock and clenched his fists, and used language that Mr. Barto would not have tolerated for a moment had he been within hearing. Then the man shambled off toward the big flume.

Some time later, as Jack was climbing up to the finished part of the dam, he heard a whistle. Jack looked up. "I wonder where that came from," he said; "it was just like a caisson sig-

nal.'' Again the whistle sounded. Presently there was a loud hissing noise, and then, from the far side of air-lock No. 7, Jim Doyle staggered into view. At once Jack scented trouble, and he ran to the caisson as fast as he could, scrambling over obstacles and leaping from timber to timber.

''Joke 'sh on Bar'o af'er all!'' shouted Jim, waving a flask, as he saw Jack coming. ''Had 'nother bot'le in the shack.''

''Mr. Barto is whistling for help, is n't he?'' commanded Jack. ''What are you doing to him?''

''Let him sh'ay there. He threw away my Chrishmash, did n' he?''

''You 're not keeping him in there, are you?'' persisted Jack. ''Something is the matter. What have you done to him?''

''It 'sh jush a li'le joke on him. He shays nothin' but water here in thish camp. Well, I 'm givin' him shome water. Shee that gage?''

Jack took in the situation at once and jumped for the air-valve. ''You drunken fool!'' he cried. ''You're letting off the air pressure!''

''Don' you butt in. It 'sh jush a joke. Let him have all the water he wantsh,'' said Jim, striking out at Jack. The boy dodged the blow,

then suddenly leaped at the man and sent him sprawling over the side of the caisson, into the icy river. At once he closed the exhaust-valve that Jim had tampered with, and then he paused to look at the man he had thrown overboard. Sobered by the shock of the cold plunge, Jim was swimming strongly down-stream to a good landing-place. Evidently he could take care of himself. But what of Mr. Barto? Again the air-whistle blew plaintively. Jack did not know how to restore the air pressure. There were several valve-wheels, but he had no idea which to choose.

"I 've got to go down, myself, and see what 's happened."

He knew what to do, for Perry had described the whole process to him minutely, and once had taken him into an air-lock that was out of service, and had shown him which valves were which. He swung a lever to close the bottom door, and then opened a valve to let the compressed air out of the lock. A moment later the upper door of the lock opened and the boy climbed in.

For the barest fraction of a moment Jack hesitated as he thought of the two men who had died of caisson disease. Then he snapped his jaws, walked over to the air-valve, turned it,

and, with considerable effort, swung up the heavy iron door. Just as he had it nearly closed, the air caught the door and clapped it shut. Jack stood in the little round chamber of the air-lock, considerably excited. It was just as Perry had described it. He felt the increasing pressure of air on his ear-drums. It was growing painful. Perry had said that he must hold his nose and mouth shut and then blow for all that he was worth. Jack tried it and got some relief, but still it seemed as if his ears must burst. Maybe he was letting the air in too fast. He reached over and closed the valve slightly.

Then he began to soliloquize: "The trap-door in the floor is held up by the greater pressure of air below. When the pressure above is the same as that below, the door will drop open."

Suddenly he jumped to one side of the chamber. "Why, I 've been standing on that door all the time!" he exclaimed.

Less than five seconds later, the door swung down, striking the side of the shafting with a bang. There was something uncanny about the way it yawned open, revealing the narrow, dimly lighted well that ran down seventy-five feet into the earth.

"Hello!" came a muffled voice from out of the depths. "Anybody there?" The voice sounded strange in that heavy atmosphere.

"It 's Jack. What 's the trouble?"

"I can't get out," came the voice again. "My ankle 's broken, or terribly sprained."

"I 'm coming down as fast as I can."

Jack saw no ladder, but he noticed a set of rungs that projected from the wall of the shafting, and he ran down them like a monkey. As he reached the bottom of the shafting, he peered down into the working chamber. Below him was a pool of black water, and, clinging to the rope-ladder just above the surface, was the chief engineer.

"Mighty glad to see you, Jack!" he exclaimed. "But I don't know what you can do here. I can't climb all the way up to the air-lock, even with your help. You will have to scare up somebody. Run over to the power-house. Williams is there. Get him to send down the bucket."

"But won't you drown in the meantime?"

"I don't believe the water will rise much higher," said Mr. Barto; "and if it does, I can drag myself up another rung or two.— My, how that ankle pains me!"

"All right, Mr. Barto, I 'll have the bucket here in a jiffy."

"Take your time now. Are you sure you know what to do?"

"Oh, yes!" answered Jack.

"Well, don't touch any of the valves outside. I thought you were going to drown me out when you opened that exhaust-valve."

"*I* did n't do that!" protested Jack. "Some one was trying to play a joke on you. He had too much liquor aboard."

"I can't imagine where they get that liquor," muttered the engineer. And as Jack hastened up the shafting, he was glad that Mr. Barto had n't asked him the name of the guilty party.

Getting out through the air-lock was just the reverse of getting in. Jack knew he must open the exhaust-valve and lift the lower door, and then wait for the air to flow out of the chamber until the upper door opened; but he was unprepared for what happened. Almost immediately a dense, white fog filled the air-lock, so that he could n't even see the electric light across the chamber. Perry had n't told him anything about fog. Could he have opened a steam-valve? But they did n't use any steam on this work. All the machinery was electrically driven. Really, Jack was quite badly frightened. How did he know what was going to happen? Was he about to feel the grip of the cais-

son disease? Could he be letting out the air too fast? He groped for the valve and closed it somewhat, to throttle the escape of air; but still the fog persisted. It was a terrifying experience. But he kept his nerve, and had the presence of mind to stand out of the way of the upper door so that, when it swung open, it did not knock him down.

A moment later he had aroused Williams and another man, and within five minutes the electric hoist was lowering a bucket into the caisson. Jack insisted on accompanying Williams and helping him bring out the engineer.

When it was all over, a more delighted boy was not to be found west of the Mississippi. The caisson disease held no horrors for him. Twice he had been "under pressure" and pretty high pressure, too, without feeling any ill effects afterward. There was no reason why he should n't go wherever Perry did and watch the progress of the work. He felt himself a veteran. Besides, he had done a rather plucky and important thing. Of course he did n't boast, and he never said a word about his tussle with Jim Doyle. Yet he had a very pleasant feeling of satisfaction when he thought it over.

But, best of all, Mr. Barto appreciated what Jack had done for him. He was shrewd enough

to guess what had happened, when he learned of Jim Doyle's cold swim, and he admired the boy for not tattling. The engineer had noticed that there had been altogether too much drunkenness in the camp of late. He would see that the prohibition of liquor was more strictly enforced. It was puzzling to know how the men kept so well supplied, when there was not a saloon within miles of the site.

After the Christmas-day adventure, Jack was more often to be seen at the camp. Mr. Barto was very much interested in him. He even drove up to Farmer Billups's house and persuaded him to let Jack pay frequent visits to the work, at any rate during the winter months when there was not so much to be done on the farm.

"That young chap was cut out for an engineer!" Mr. Barto declared. "It 's too bad he has n't a chance to study."

Perry rigged up a flag signal, that Jack could readily see from Eagle Bluff, which notified him when any work of special interest was going on. It was in response to such a signal that Jack came down to see them pump out the big cofferdam. Enormous timber-braces reached across from one side to the other to prevent the water from crushing in the timber walls. The bed of

"WE'VE UNCOVERED A NUMBER OF CAVES DOWN THERE, AND THE WATER IS POURING FROM THEM."

the river exposed within the coffer-dam showed huge masses of concrete and pieces of twisted steel, relics of the foundations of the first dam.

"It 's going to be a nice job cutting up those lumps and steel girders so that they can be hauled up," Jack volunteered.

"Yes," agreed Perry, "but not half as hard as it was to get them out of the caissons when we were lowering them to rock. We had to cut the steel with the oxyacetylene torch."

Two weeks later Jack hurried down to the camp again in response to an urgent signal. Mr. Barto, on crutches, with Perry at his side, was looking down into the big coffer-dam.

"What do you suppose, Jack?" cried Perry. "We've uncovered a number of caves down there, and water is pouring from them almost as fast as it can be pumped out!"

"Where does it all come from?" asked Jack, of Mr. Barto.

"Well, I don't quite know," replied the engineer. "I hope it is from the river. But if it happens to come from some source high up in the mountains, it may give us a lot of trouble."

"Why, what 's the difference?"

"A difference of pressure. There can't be a head of more than seventy-five feet if the water

comes from the river. That means a pressure of about thirty-two pounds per square inch. But if it should come from the top of the mountain with a head of three thousand feet, there will be a pressure of nearly thirteen hundred pounds per square inch."

"But do you have to stop it, Mr. Barto?" asked Perry. "Why not let it go?"

"My dear boy, you ought to know what running water will do! Jack, here, can tell you how it got under the first dam, and how it ate out the foundations. We are not going to let anything like that happen again if we can help it."

"But what *are* you going to do?"

"We 'll have to dam the streams," answered Mr. Barto.

And this is how it was done: channels were cut in the face of the rock leading from one cave to the other, while a big steel pipe was set in the mouth of the lowest and largest cave. Then a concrete wall was built over the face of the rock, sealing all the caves, while all the water gathered in the lower cave and poured in a big stream out of the pipe. At the end of the pipe there was a valve, while just behind it there was a stand-pipe leading up to a little above the normal level of the river. When all was ready, the valve was shut, and the water, suddenly checked, surged up

the stand-pipe. Cement was then pumped in through this pipe to plug and seal the big main.

This was the last serious difficulty encountered in the building of the foundations of Thunder Creek dam. Everything went smoothly after that. But an incident occurred, just before the caves were walled off, that is worth recording. Perry and Jack made a most surprising discovery. Because of his lame ankle, Mr. Barto had to depend upon Perry for many things that ordinarily he attended to himself. He had Perry inspect the rock of the caves, and Jack, who happened around just then, went along. The largest of the cavities was close to caisson No. 1. It was about six feet high and appeared to be not more than ten feet deep. But when Perry began prying around with a big iron bar, he loosened a rock, beyond which there appeared to be a still larger cavity. Excited by this discovery, both boys began crumbling away the rock until they had opened a passage large enough for them to squirm through.

"This looks like a big cave!" cried Jack.

"Let 's get a candle and explore it," suggested Perry.

By the light of the candle they were able to see that this was a broad corridor, carved out

by nature, and that it rose very steeply, with a rough, broken floor. There were not many branches in the corridor, and it ran fairly straight, so that they had no fear of losing their way. At times it narrowed so that they could barely get through, and once or twice they had to creep along on hands and knees. They had progressed slowly for perhaps a quarter of a mile when the passageway suddenly contracted to a mere fissure that they could n't possibly squeeze through. Jack climbed up the face of the rock to a point where there was a slightly broader opening through which he could look into the mystery beyond.

"Do you see anything?" inquired Perry. "Don't you want the candle?"

"No; I believe I see daylight. We must be near the mouth of the cave. *'Sh-h!* I hear some one coming."

Perry put his ear to the fissure and listened. He heard a voice say: "Hello! Kelly must have been here last night. He 's taken his money and brought us a new stock."

The voice sounded like Jim Doyle's.

"But does he leave the stuff with no one to watch it?" said another voice.

"Sure!" replied the first man. "And why not? He treats us square, and we treat him

square. If it wasn't for him, we'd have a pretty dry time in camp—they're so strict; but Kelly, he comes up here at night with a load of bottles and a box for the silver, and he knows that when he comes back again there'll be a half-dollar in the box for every bottle taken."

The boys heard the men drop a couple of pieces of silver into the box and then walk out of the cave.

"Well, we've discovered something that Mr. Barto will be glad to hear," declared Jack.

"Yes," rejoined Perry. "We've discovered the back door. But it's locked. How can we find the front door?"

"I know where it is!" cried Jack. "It must be that cave right outside the camp limits."

"I never knew there was a cave there," said Perry.

"What! Don't you know that big rock just past the bend? The one with a pine-tree each side of it? Well, behind that rock there is a hole that opens up into a good-sized cave. I've been in there often, but not lately. It must be this same cave. Don't you think so?"

"Let's go round and see," suggested Perry: and they found that Jack was right.

The next day the lower end of the corridor

was closed by a big plug of concrete, so that the water should not back up through it and, finding its way through other fissures, continue its undermining operations. On the same day, the hole in the rock along the highway was also closed by a wall of concrete to prevent the flow of liquor, with its consequent undermining effect upon the workmen. Thereafter, there was a long period of drought in Thunder River camp.

CHAPTER II

BURIED ALIVE

A YEAR and a thousand miles separate this chapter from the last. To Jack Winans the year seemed like ten and the miles like ten thousand, for he had dragged himself, painfully, over much of the distance on foot.

Mr. Barto's work at Thunder River was long since completed. After the pit inside the ring of caissons had been carried down to rock, work on the foundations had moved along so briskly that by the end of May they were finished. To be sure, the main body of the dam was still to be built on them, but that part of the work did not concern Mr. Barto, so he dismissed his men, struck camp, and taking Perry with him as his private secretary, went to look into a big piece of engineering somewhere in California.

Not until they were gone did Jack realize how much the two had meant to him. He could n't attend to his work, which made Farmer Billups grow more and more irritable, until finally Jack could stand it no longer.

Then, one day, a letter came to him from Perry. Mr. Barto and he were in Los Angeles at the Hotel Sequoia. "I wish you were with us," Perry had written. "I don't know whether you will ever make a good farmer, but I am sure you 'd make a bigger success at engineering."

That settled it for Jack. He would go out into the big world after his friends. So one summer night he penned a note of farewell to Aunt Judy, packed up his most treasured belongings, shook out the few coins in his savings-bank, stole out of the house, and tramped five miles across country to Coogan's Siding, where he crept aboard the west-bound freight as it waited for the "Snow-crest Limited" to thunder by.

We have n't room to describe Jack's experiences during the long months that followed. He had to work his way, of course, and that took lots of time. After the first night, when he was anxious to get away as far as possible before morning, Jack Winans stole no more rides on freight-trains.

"They 'll think I 'm a hobo," he said to himself. "But I 'm not in that class. I can pay my way, thank you."

That meant that he had to stop off and work

JUST AS JACK REACHED THE EDGE OF THE TRENCH, THE EARTH GAVE WAY BENEATH HIM.

until he had earned enough to carry him along the next stage of his journey. That is why it took him eight months to reach his destination.

It was the middle of February when he finally arrived in Los Angeles and inquired at the Hotel Sequoia for his two friends.

"There 's no one by that name here," snapped the clerk.

"But they were here last June," persisted Jack, "because I got a letter from Perry Carpenter sent from this hotel."

The clerk consulted the register. "Oh, yes," he said, " they were here just two weeks, June second to sixteenth. Then they left without saying where they were going."

"I don't believe they got my letter saying that I was coming. Let me see," Jack reflected. "June sixteenth? Why, that 's the day I started!"

"Started!" ejaculated the clerk. "Where from, Timbuctoo? You could go around the world six times in eight months."

"But you could n't do it if you started with less than two dollars in your pocket and had to stop off every twenty or thirty miles to earn your car-fare and lodging," Jack retorted.

"Could n't you hook a ride?"

"I 'm no tramp!" declared Jack. "I paid

for my car-fare all the way, except the first night when I was anxious to get across the State line as quickly as possible. And I 'm no outlaw, either,'' continued Jack, as he noticed a look of suspicion flash across the clerk's face. Then he proceeded to lay bare his life's history.

''Now the first thing I 've got to do,'' Jack went on, ''is to find a job, because my pocket-book is getting rather flabby. Then I can look up Mr. Barto and Perry Carpenter. Is there any big engineering job around here?''

''Big? Well I should say so. The biggest piece of work this side of the Rockies. Have n't you heard about the great Los Angeles Aqueduct, two hundred and thirty-four miles long?''

''Two hundred and thirty-four miles!'' exclaimed Jack.

''Yes, it 's the longest aqueduct in the world. It beats the Catskill Aqueduct, in New York, by a hundred miles. The water comes from the snow in the Sierras and runs through miles of concrete flumes and steel siphons and rock tunnels; there are a hundred and fifty tunnels along the line, and one of them is five miles long. Yes sir! this is a big job all right!''

Jack brightened. ''Then they must be build-

ing the aqueduct," he said. "When did the work start?"

"Start?" exclaimed the clerk. "Why, it 's all finished except the power-plants. You know, they are going to make use of the water to generate electricity. There is a drop of something like thirty-four hundred feet between the source in the Sierras and the outlet in the San Fernando Reservoir. Now your friends might be working on that job. I would advise you to go to the chief engineer's office and inquire. It is only about five blocks away."

At the chief engineer's office Jack was unable to learn anything about Mr. Barto and Perry. Certainly they had never had anything to do with the aqueduct. Furthermore, there was no sort of a job open for Jack. It was a day of bitter disappointment. This was the outcome of his thousand weary miles of travel. For the first time since he left home, Jack faltered. But he could not sit down and mope. Only a few pieces of silver jingled in his pocket. He must find a job without delay, and then he could afford to stop and consider his next step.

He tried a number of places without success. Finally, night overtook him and forced him to part with a large portion of his capital for a bite to eat and a place to sleep.

Early the next day he was at it again, after consulting the "Help wanted" section of a morning paper. Near the outskirts of the city he came across a street that was ripped open, while a gang of men were laying a big water-main. The prospects did not look very promising. Nevertheless, he marched into the construction shanty and applied for a job.

"The only job we have here is carrying water," he was told.

"I don't care what the work is, so long as it is honest work," replied Jack. "I 'll take the job."

And so Jack became a water-boy, and had to tramp along the trench in the broiling hot sun with a pail of water and a dipper, refreshing the parched workmen.

There was nothing very interesting about his task. At one end of the line the men were digging the trench and shoring up the sides with planks; at the other end they were filling it in. Between these two extremes the sections of cast-iron pipe were being laid. Under each joint the floor of the trench was dug out a little so that the calkers could get at the under side of the joint and drive the packing into the bell of the pipe. Farther back, they were cementing the joints which had been calked.

As Jack swung along with his heavy bucket, he overheard two of the calkers who were engaged in a heated argument. One of them was lying on his back and reaching into the depression under the pipe, while the other, a red-headed chap, sat astride the pipe above him.

Just then the man under the pipe raised himself and turned his head. Immediately Jack recognized him as Jim Doyle, the man he had knocked into Thunder River. He was so delighted to see a familiar face again that he did n't stop to consider how he might be received, but ran forward crying "Hello, Jim!"

Apparently Jim did n't hear him, for he kept right on with his argument. Then something happened.

Just as Jack reached the edge of the trench, the earth gave way beneath him. He reeled, and the pail of water flew out of his hand. The shoring burst apart, and an avalanche of sand poured into the excavation bearing Jack on its crest.

"Look out, Jim!" he yelled; but Jim had n't the slightest chance. Jack caught the startled look of his old acquaintance as he struggled up to a sitting posture. Then the sand closed over the man, and Jack found himself at the bottom of the trench, half buried, beside the red-headed

chap who had been sitting astride the pipe.

Both of them shouted a wild cry for help, but already men were coming from all directions.

"Hurry!" cried Jack, as he struggled to free himself. "There 's a man buried under there! It 's Jimmy Doyle. Here, give me a shovel!" But he was swept aside, while more experienced hands dug away furiously at the sand.

Jack was almost frantic. He felt responsible for the accident. "How long can he live under the sand?" he asked the foreman.

"Well, two minutes is pretty close to the limit," the man replied as he looked at his watch, "and he 's been down there about that long already. No man could stand it much longer than that."

"But why don't they hurry? They are n't making any progress!"

"Just you keep cool, young feller. Jim Doyle is probably done for, but you can't do any good by gettin' excited! The boys are shoveling it out as fast as anybody could.

"Here, Rafferty!" he shouted, "put in some planks there to keep back that sand; it 's sliding in faster than you can dig it out." Some of the men began to drive planks endwise into the sand to hold it back. Jack ran around perfectly

distracted. All he could see was that startled look on Jim Doyle's face just before the sand closed over him.

"What time is it? How long is it?" he kept pestering the foreman.

"Eight minutes gone," said the foreman, closing his watch with a snap. "It 's no use. He could n't possibly live half that long."

Jack gave up in despair, when he was roused by the shout, "Here he is!" They had uncovered the top of the man's head and were digging the sand from around his face. Jim Doyle's head was apparently jammed against the pipe.

A sickening horror seized Jack. He was about to turn away, when a most uncanny thing happened. The head suddenly lifted, the eyes opened and looked straight at Jack.

"Hello!" shouted Jim Doyle; "glad to see you, Jack! But the next time you call, don't tell me you 're here with a pail o' water and a hundred tons o' sand!"

Everybody burst out laughing. As for Jack, he was almost in hysterics at this sudden relief from the tension to which his nerves had been subjected.

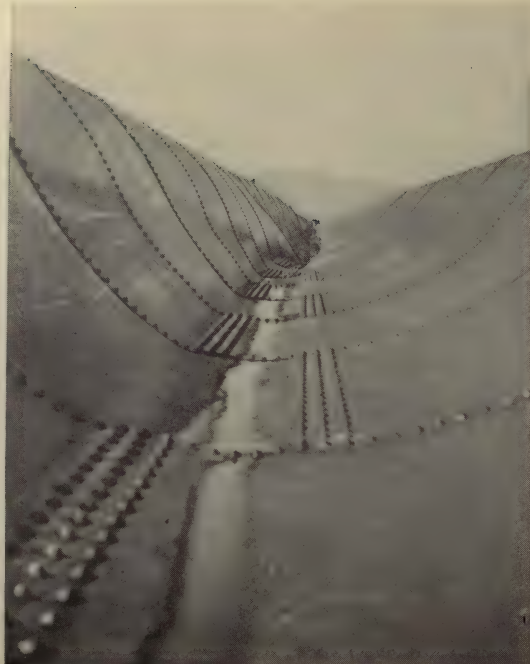
"How did you do it? How could you hold

your breath so long?" Jack managed to gasp.

"I did n't hold it," laughed Jim. "I had all the air I wanted."

"But where did you get it from?"

"Why, from the pipe, of course. As soon as I saw I could n't get out, I clapped me mouth to the joint where it had n't been calked yet, and I got all the air I needed."



Photographs by Burt A. Heinly.

THE COLLAPSED SIPHON.

WHEN THE WATER WAS FIRST TURNED IN.

CHAPTER III

THE "WATER-CURE" FOR A FLATTENED PIPE

JACK'S job as water-boy did not last very long. The sewer was soon completed and he had to look about for something else to do. Despite their previous unpleasant encounters, Jack and Jim Doyle had struck up quite a friendship. They both stopped at the same lodging-house.

"Oh, I don't bear you any grudge," Jim Doyle said once, when Jack referred to the episode of the air-lock. "You saved me from a bad bit o' crime when the whiskey had turned me head, did n't you?"

"But did you know it was Perry and I who found the whiskey cave?" asked Jack.

"So you were the rascals, were you? Well, you did me a good turn there too. I could n't keep straight with all that liquor so handy." Jim Doyle was really trying to keep away from drink and Jack did his best to help him.

The day after the work ended on the pipe-line

it rained so hard that they could not go out to look for another job. It rained as it had never rained before in the memory of the oldest inhabitant. The next day was even worse, and on the third day the clouds continued to pour down their floods upon the city. Streams were swollen and overflowed their banks, carrying away bridges and washing out roadways. Los Angeles was cut off from the outside world.

It was impossible to seek work in such a storm, although Jack did try several times.

"Don't you worry, me boy," counseled Jim. "This storm is *making* work for us *somewhere.*"

Jim was a better prophet then he realized. A most interesting piece of work was awaiting them. The storm was very wide-spread. It reached out to the edge of the Mojave Desert, and streams that had been dry for years now ran yellow with angry torrents. In the Antelope Valley, about fifty miles from Los Angeles, the great aqueduct, on its concrete legs, crossed one of these ancient stream-beds; but an angry river now beat against these legs and they were soon undermined and toppled over on their sides. This caused a wide breach in the big steel pipe, letting the water flow out.

Jack read the news in an extra. "There 's

the work the storm has brought us!" he cried. "Come on, Jim! Let 's apply for a job."

Together they went down to the City Bureau of Water Supply. They were the earliest arrivals and were given first place on the list of applicants. The next day Jack secured the job of timekeeper, while Jim qualified for work on the concrete piers. Jack was very glad he did not have to serve as water-carrier, particularly after he had traveled all day in a wagon across the desert to the scene of the accident and found out what a fearfully hot place it was.

Antelope Valley was about five miles wide. A large siphon, ten feet in diameter, carried the water down into and up out of the valley. On the north side there was a drop of about 200 feet, while the rise on the south side was about thirty feet less. Most of the siphon was in the form of a heavy steel pipe, but near the top of each slope the steel merged into a reinforced concrete pipe. What puzzled Jack was that the most serious damage was done, not at the point where the torrent had carried away the concrete piers, but far beyond the utmost limits reached by the flood. The pipe was in good condition for a half mile or so on each side of the break; but from there on to the concrete conduit the steel pipe on each slope had collapsed, the top

sinking in until it looked like a deep trough.

"I can't understand it," said Jack to Mr. Thorpe, the assistant engineer. "What happened to the pipe anyway? Is the steel so thin that it can't stand up alone, and has to be swelled out with water?"

"It was the air that did that," replied the engineer.

"The air!" exclaimed Jack. "That 's too much for me. What do you mean?"

"Why the air-pressure!" exclaimed Mr. Thorpe.

"But where does it come from?"

"Come from? Why it 's here all the time, all around us. Don't you know that the air-pressure on the outside of your body is something like twenty tons?" Jack looked skeptical.

"Well, I don't know *just* how much," continued Mr. Thorpe. "I have n't measured you. But it is fifteen pounds on every square inch of your body."

"But why don't I feel it then?"

"Because there is just as much pressure inside to withstand the pressure outside; otherwise you would flatten out like a pancake. This pipe is ten feet in diameter, and the atmosphere is pressing on the outside with a weight of fifteen pounds per square inch, which puts a load

Photographs by Burt A. Heinly.

THE PIPE ROUNDING OUT.

THE PIPE FULLY ROUNDED OUT.

on it of about a hundred tons per running yard. When the siphon was first laid, the air on the inside of the pipe resisted the pressure on the outside; then when the water was turned on, it more than took the place of the air-pressure inside. When the break came, the other day, the water ran out so fast that it took away a big share of the inside pressure without letting in any air to take its place; and then the outside atmosphere just crushed in that pipe as if it were made of tin. Why, at the upper end of the north section it actually tore out a couple of plates, so that we must replace them!"

"But you will have to replace all of this pipe, won't you?" asked Jack.

"Oh, no! that would be too expensive. I think we can get along without doing that. The pipe collapsed because the water shirked its duty and ran away. Now we 'll see if we cannot make that water repair the damage."

"How?" Jack was consumed with curiosity.

"You just wait and see!" was all the satisfaction that he could get.

The first task was to replace the two concrete piers. Jack hung around during all his spare moments and watched the work.

"I don't believe they knew what they were about," he said. "If they had put their foun-

dations down to rock in the first place, this would not have happened."

"Since you know so much about it, why don't you go up to the chief engineer and give him some advice?" suggested Jim.

"Well, I know something about foundations and what Thunder River did to them, don't I?"

"Well, this isn't Thunder River. How about it, Mr. Thorpe?" said Jim, turning to the assistant engineer, who had just come up. "Jack, here, thinks you ought to have carried those piers down to rock."

"To rock? Well, maybe; but these piers were not put down to carry the siphon over a river. Why, there hasn't been a trickle of water in this stream-bed for years! This is a desert. We may not have another drop of rain here for a year, and then there won't be enough water to wet the soil. Before the storm you'd scarcely have known that there had ever been a stream through here. When we put down these piers, we never anticipated a three days' downpour, and the chances are there won't be another rain like this in the next hundred years."

While the work was proceeding on the piers, steel plates had been ordered from the mill. They were rolled cold, to the exact curve of the

siphon, and the rivet holes were punched in them before they were shipped. Only just enough plates were made to replace the torn ones in the pipe-line at the bottom of the valley and also on the northern slope. In due course of time they arrived and were riveted into place.

One morning, when everything had been completed, Mr. Thorpe called to Jack to come along. "We are going to try our little scheme," he announced, "of using the water to undo the mischief of the air."

"Where is the apparatus?" asked Jack, looking eagerly about.

"There," said Mr. Thorpe, pointing to the siphon.

Jack could not see anything. "But I don't understand. Are you going to use hydraulic jacks or something?"

"Yes, that 's it," replied the engineer, enjoying the bewilderment of the boy; "but the pipe itself is the jack."

"You don't mean—" began Jack, as a light began to dawn on him.

"Yes; I mean we are going to give the pipe the 'water-cure.' We 'll turn on the water and let it inflate the pipe just as you would inflate a tire with air."

"But it will take an enormous pressure, won't it?"

"It did n't take more than fifteen pounds per square inch to collapse the pipe, and probably much less. We can get five times that pressure when we fill the pipe full of water."

"But won't the plates break from bending?"

"Well, it is good tough steel; it ought to stand the strain, particularly as there are scarcely any kinks in it. What we are most worried about is how the riveted joints will stand it."

Jack was assigned a patrol along the northern slope to watch the action of the siphon when the water was turned on. He walked back and forth in the trough of the collapsed pipe. Presently he noticed that the trough was gradually rising and at the same time flattening out. It was very slow work, however. After many hours the siphon began to take on an oval form. It was a ten-foot pipe when round, but now, in the oval form, it was 14½ feet in diameter the longer way. Of course the pipe was not of the same shape throughout its length. The first effect appeared at the lower end, and then gradually worked up the slope to the top as the siphon slowly filled with water. Finally the full

Photograph by Burt A. Heinly.

THE COLLAPSED ANTELOPE VALLEY SIPHON RETURNING TO SHAPE AFTER THE WATER WAS TURNED IN.

pressure was reached, and then the siphon came to true, round shape.

It was a grand success. The riveting of the plates stood the strain remarkably well. Long stretches of the pipe needed no attention whatever, and in a few places a little calking stopped the stray leaks.

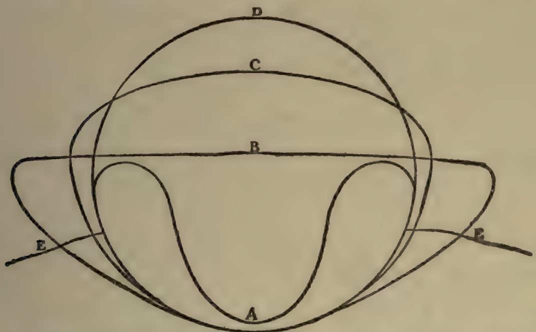


FIG. 3. DIAGRAM SHOWING THE COLLAPSED AQUEDUCT AND THE SHAPES IT ASSUMED AS IT FILLED WITH WATER.

A, Collapsed position of pipe; B, Position taken at beginning of filling; C, Position after filling; D, Original and final position of pipe; E, Surface of ground.

"It provides a very good demonstration of a problem in geometry," said Mr. Thorpe to Jack, after it was all over. "I suppose you have been told that a circle will cover a bigger area than any other boundary of the same length. I took careful measurements during the operation and here is the way the pipe behaved."

Mr. Thorpe exhibited a sketch similar to Fig. 3.

"First it had a regular U section; then it broadened out so that the top was flat; then it became an ellipse, but still it had n't reached its fill. Finally it became a circle, and that was the limit of its capacity. No other shape would let more water through."

CHAPTER IV

JIMMY DOYLE'S STORY

JIM and Jack were walking down Main Street, The Antelope Siphon repairs were finished, and they were back in Los Angeles looking for work again.

"Have we got to wait for a cyclone to blow us another job?" asked Jack.

Jim Doyle grinned. "Mebbe!" he said. "Or, it might be an earthquake this time."

Just then he was nearly knocked off his feet by a tremendous thump on the back. "Hello, Jim!" cried a husky six-footer. "Hain't seen ye in five years; what yer working at here?"

"Presarve me from me friends!" exclaimed Doyle, as he slung around to meet his assailant. "Och, but ye 're powerful hearty with yer fists, Kelly! I thought it was the earthquake we was just talkin' about."

The big man laughed.

"Ye never can tell how yer friends are going to greet ye," continued Doyle. "Look at this lad now," turning to Jack. "He looks harmless

enough; but how do ye suppose he showed his pleasure at seeing me? Why, by throwing a bucket o' water at me and then buryin' me under a car-load o' sand. It would have killed me if I had n't clapped my mouth to a joint in the water-main I was calkin'."

"Oho!" exclaimed the big man. "So you 're the hero I read about in the 'Frisco papers last month, are ye?"

"Ye don't mean to say it got into the papers!" ejaculated Doyle.

"Sure thing! On the front page."

"Huh!" Jim grunted. "Well, that 's the feller that done it. Shake hands with me friend Kelly, Jack," said Doyle. "Flat-wheel Kelly, we call him; but watch how he grips yer hand."

Jack put all his strength into that hand-grasp to offset the viselike grip of the giant Kelly. "What a queer nickname!" he thought. But he understood it all later when Kelly walked off. His peculiar sliding, thumping gait reminded one at once of a flat-wheeled trolley car.

"He mashed his leg in a slide o' rocks," Jim Doyle explained to Jack later. But now they were talking about the work they had been doing. Doyle was saying that they had just finished the biggest aqueduct in the world, with-

out bothering to explain how little of the work they had really done.

"Oh, ye have, have ye?" answered Kelly. "Well, then, ye 'd better tackle the biggest electric power-plant in the world next. I jest come from there to look for somethin' more interesting."

"What power-plant do you mean?"

"Why, have n't ye heard of the Big Creek plant? They are going to use the highest head of water on record, and send the 'juice' they make all the way to this town—240 miles, at 150,000 volts, the highest voltage ever used for sending electricity acrost the country."

"Is there any job for us there?"

"Should n't be s'prised. Come on in," turning toward a saloon, "and let 's talk things over."

Jim Doyle shook his head. "Nothin' doin'," he said. "I 'm on the water-wagon now."

Kelly stopped aghast. Then he winked at Jack and burst out into a loud laugh. "Ye got me that time, Jim. Ye 're up to yer old tricks. I thought ye really meant it at first."

"But I *do* mean it," persisted Doyle.

"What!" gasped Kelly; "that sand got inside yer head, eh?"

"No, it wa'n't the sand as did it, but just a

young feller like this Jack, here. I can see his face now, all red with the glow o' the bonfire, peering at me through the black night, with the waters of the Rio Pinto up to his chin an' tryin' to tear him loose from the bit o' rock he was clingin' to, an'—''

Kelly shook his head at Jack and tapped his forehead sadly. ''Cheer up, Jimmy,'' he interrupted. ''Where do ye live? I 'll drop around to see ye sometime.''

Jack gave him the address, and the big man shambled down the street with that peculiar ''flat-wheel'' gait.

''What were you saying about the face out in the water?'' questioned Jack, consumed with curiosity as to the mystery of Jim's reform.

''Oh, I 'll tell ye all about that to-night. But now we must be hunting up a job.''

That evening after dinner, Jack prevailed upon Doyle to recount the thrilling experience that had made such a marked change in his life.

''It was down on the Rio Pinto, in Brazil,'' he began. ''You remember I left the Thunder River job early in the spring, when I took the first train east. Well, after awhile I got to New York, an' there a friend of mine put me wise to this job down in Brazil. When I got to the Rio Pinto, I found there was n't a dozen white folks,

an' the rest was picked up from all over the world—a lot of 'em black as the ace of spades, but there were Portuguese, Italians, Indians, even Chinese, an' one feller was an Arab—Ali something-or-other. We called him Al for short. The job was to build a dam across the river, an' an ugly stream it was, plumb full of boulders that split open the water an' made it boil an' foam an' swirl, an' many o' the rocks was just covered enough to rip the bottom off a boat. But pshaw! no boat could sail down that stretch o' river; no canoe, even, had ever tried to shoot them rapids.

"They was buildin' a big flume to carry the water past the place where the dam was to be—about as big as the flume at Thunder River. The only way to get acrost the river to the work on the other side from the camp was to walk up-stream about two miles to a bridge. But when I got there, they had stretched a cableway acrost to carry the materials."

"A cableway?" interrupted Jack. "What 's that?"

"Why, a wire cable stretched acrost the river, with a skip hangin' from a carriage that runs on the cable."

"A carriage?" queried Jack.

"Yes; a set o' wheels that run along on the

cable, an' the skip hangs down from 'em. There is a conveyin'-rope to pull the carriage along the cable out to where you want it."

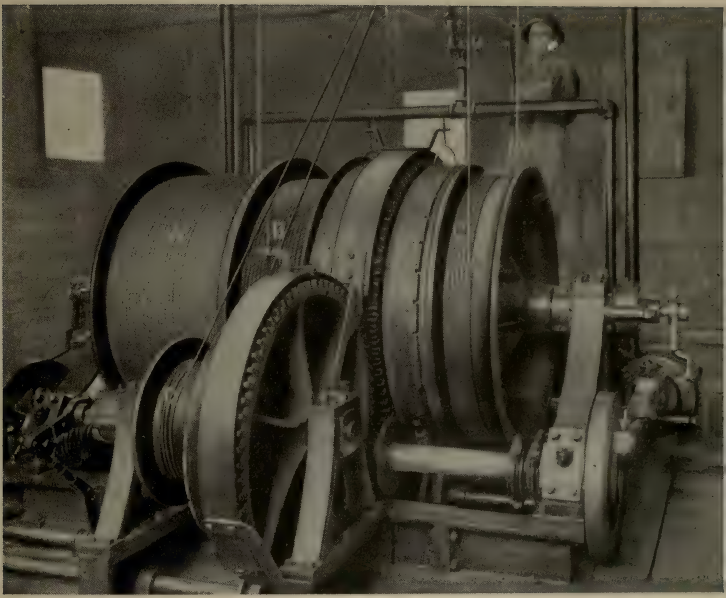
"How do you push the carriage back again?"

"Push it?" laughed Jim. "Say, but ye 're thick-headed to-night, Jack! Here—give me a piece o' paper, an' I 'll draw ye a picture of it."

(Jim was not much of a draftsman, and his sketch was very crude, but it served the purpose. The reader can probably follow his explanation better by looking at Figures 4 and 5.)

"Ye see, the conveyin'-rope is endless," explained Jim. Then, with good Hibernian logic, he proceeded to explain that the two *ends* of this *endless* rope were fastened to the carriage. "One end," he said, "is fastened to the for'ard end of the carriage; then the rope runs acrost the river over a sheave on the tail-tower and comes back to the head-tower. From there it runs down into the engine-house, takes a few turns about the conveyin'-drum on the engine, an' runs back over the head-tower to the hind end of the carriage. When the conveyin'-drum runs one way, it pulls the carriage by the hind end; an' when it runs the other way, it pulls the carriage by the for'ard end. That 's simple, ain't it?"

"Yes, I see," said Jack.



INTERIOR VIEW OF HEAD-TOWER ENGINE HOUSE.

A, Hoisting-drum; B, Dumping-drum; C, Conveying-drum; D, Tipping-drum.

"Well, then," continued Doyle, "there is another rope for hoistin' an' lowerin' the skip. This runs from the hoistin'-drum over a sheave on the head-tower an' out to the carriage. There it runs down through a pulley-block that the skip is hooked onto. [See Figure 5.] So, by workin' the hoistin'-drum, the skip can be raised or lowered. One end of the skip is held up by another block an' a rope that runs to a drum alongside the hoistin'-drum. This is the dumpin'-drum, which is really part of the hoistin'-drum, the hoistin' an' dumpin' sections bein' separated only by a flange. Now these sections bein' the same size around, the two ropes are paid off at the same speed, keepin' the skip level. But there 's a lot o' slack in the dumpin'-rope, an' the slack is taken up by a sheave on the end of another rope that 's wound on another drum, an'—"

"Hold on there!" cried Jack. "You 're getting me all twisted. How many drums are there now?"

"Only four—one to move the carriage back an' for'ard, one to hoist an' lower the skip, one for the dumpin'-rope that 's fastened to one end o' the skip, an' a little feller that puts in a bit of extra pull on the dumpin'-rope an' tips the skip, dumpin' the load. Ain't that simple?"

"Yes, I guess that 's clear enough," agreed Jack. "I think I know all about cableways now."

"Oh, do ye?" exclaimed Doyle. "Well, I have n't told ye about the most important part yet. Ye see, a cableway has to run acrost a purty big span sometimes. This span down on the Rio Pinto was only 850 feet, but they do run up to 2000 feet an' over. With a long span, the hoistin'- an' dumpin'-ropes might sag so much that they 'd weigh heavier than the skip an' then you could n't lower the skip at all. So they have hangers, for holding up the ropes, all along the cableway; they call 'em fall-rope carriers. A lot of these carriers set on a 'horn' that sticks out from the hind end o' the carriage. The carriers are all threaded on a rope above the main cable, but the eyes the rope is threaded through are not all the same size. The one nearest the carriage has the biggest eye, an' the next is a shade smaller, an' so on. Now, on this rope there are buttons of different sizes to match the eyes on the carriers. When the carriage runs out from the head-tower, pretty soon it comes to one of them buttons that passes through all the carrier-eyes except the last one. So the button ketches that carrier an' pulls it off the hook. The next button, a little ways off,

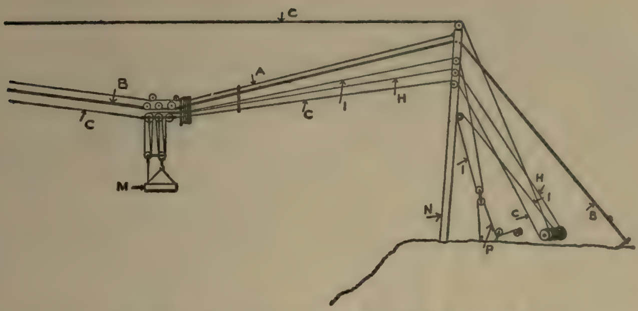


FIGURE 4. HEAD-TOWER AND CABLES.

A, button-rope; B, B, main cable; C, C, C, C, conveying-rope; H, H, hoisting-rope; I, I, I, dumping-rope; M, skip; N, head-tower; P, skip-tipping rope.

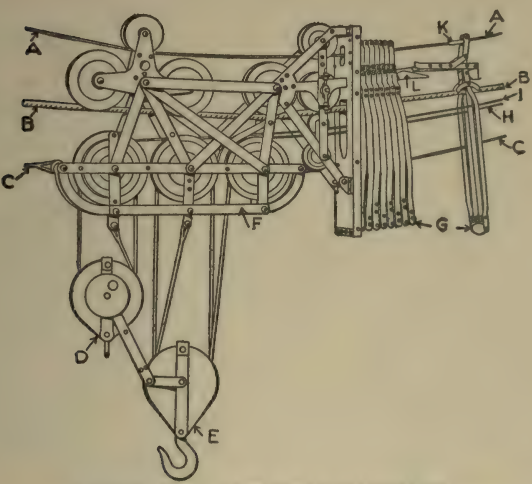


FIGURE 5. A CABLEWAY CARRIAGE.

A, button-rope; B, main cable; C, conveying-rope; D, dumping-block; E, hoisting-block; F, carriage; G, fall-rope carriers; H, hoisting-rope; I, dumping-rope; K, button; L, horn.

being a little bigger, catches the next carrier, an' so on, until the carriers have been spread along the whole cableway. When the carriage comes back, the horn picks up the carriers one by one."

"And these carriers support the ropes?" asked Jack.

"*That 's* the idea! The cable an' the ropes pass through the carrier," went on Doyle. "When it slips off the horn, it rests on the button-rope, an' the lower part of the carrier has three long slots with a sheave at the bottom of each slot for the conveyin'-, hoistin'-, an dumpin'-cables to run on."

Jim Doyle stopped as though he were all through talking.

"Go on," urged Jack. "I want the story."

"Oh, yes! As I was sayin'," he began again, "when I got to the Rio Pinto, the engineer was down with a fever an' they needed some one to work the cableway engine. Well, I chucked a bluff that I 'd been an engineer once an' could take charge of that engine. Of course I had never handled a cableway engine before; but engines is pretty much alike, an' I soon got the hang of this machine. So I got the job of tendin' the cableway, and Al, being a bright feller, if he *was* a heathen, was my helper.

"SOMETHIN' CAUGHT MY EYE OUT IN THE RIVER."

"At first they would n't let the men ride acrost on the cableway, not trustin' me an' fearin' I might make a mistake an' dump 'em into the river; but after I had been at it a week an' they found out how careful I was, they let the men go acrost; but they always had a white man in the skip to see that them furrin fellers did n't lose their heads.

"Things went along all right without a hitch for two weeks. Then somethin' happened. It all come o' tryin' some o' the native liquor; I don't know what they put in it, but it 's the worst stuff ye ever tasted. I 'd never 'a' thought o' drinkin' it if there was anything else to be had; but I took some that afternoon. It went to me head, all right, but I thought I could stick it out till night. Well, the whistle blew, an' I begun takin' the men acrost. Things went all right until it come to the last load. It was dark by that time. You know down in the tropics, when the sun sets, there ain't any twilight —it gets dark right away. Well, I got the signal to haul the load over, an' I got 'em started. I could just make 'em out in the dark. Then somethin' queer come over me. I thought I saw the signal to lower, an' I paid out the hoistin'-rope. They was right in the middle of the river. The chief engineer himself was on that

skip. I heard him shout somethin' to the men. He was tellin' 'em to hold on to the chains, because the skip might tip over when it hit the water; at the same time he took out his pocket-han'kercher' an' waved the signal to hoist. I was too fuddled to know what I was doin', an' I pulled the dumpin'-lever. Al came runnin' up just then; he knew what was the trouble with me, an' pushin' me out o' the way, he jammed the levers back again. He was too late, though; the skip had dumped just as it struck the water, an' it turned clean over, leavin' the men hangin' to the chains like wasps. Al hoisted them up clear of the river an' then hauled them over to shore.

"But one young feller, a Portuguee, had n't been quick enough to catch the chains an' was carried off down-stream, yellin' fer help. Nobody thought he could keep alive a minute in that boilin' water, but he kept hollerin' away. I ain't got a clear notion of just what happened, but I remember hollerin' back to him that I was comin', an' I run down the river. I was in no fit condition to run, an' first thing I knew, I had fallen into the river meself an' was swept off me feet. That sobered me; but before I could get out, I ran my head plumb ag'in a rock."

Jim paused and stared vacantly into space.

"Don't stop!" urged Jack, impatiently.

"Oh, yes! When I come to," Jim continued, "I could n't imagine what had happened. There was a big fire acrost the river, an' a gang of men dancin' around it, an' playin' leap-frog, an' squat-tag, an' all such fool stunts. One feller was playin' a tune on a banjo, an' another was dancin' a jig. I could n't make it out at all! They looked like imps in the red light o' that fire. I saw Al among 'em an' a lot of the rest of the fellers. Then somethin' caught my eye out in the river. It was a head stickin' out of the water. Yes, sir, it was the Portuguee! He was holdin' on to somethin' out there in the river, but the water was up to his neck an' doing its best to carry him off. I found out afterward that he 'd happened to run astraddle of a hidden rock, an' he hitched fast to it. He was all right if he could only keep hold o' the rock.

"It was Al as had found him, an' he built a fire, first on my side o' the river just to hearten up the lad, an' then, because the Portuguee was nearer the other side, he got a gang of men to run up-stream an' around over the bridge to the other side. Then he got up a sort o' vorderville show to take the lad's mind off himself an' keep up his nerve. There wa'n't no chance of savin' him that night. The best they could do

was to keep up his courage till mornin'. All night long the men kept up their pranks, jokin' with the Portuguee an' tryin' to make him laugh. I can never forget his face lit up by the glow o' the fire, the angry river beatin' against him an tryin' to wrench him from the rock. It 's good the water was warm. He could n't have held on an hour in cold water, like Thunder River, even in summer-time. I just set there an' watched him for hours."

"Why did n't you go over to the other side?" asked Jack.

"Well, as matter o' fact," replied Doyle, "I thought it would be healthier for me to stay on me own side o' the river. So I just set there, an' set there, watching that face in the water. An' I was bein' cured o' drink. Yes, sir; I ain't ashamed to say it. I vowed, if he ever come off alive, I would never touch another drop o' liquor. But I could n't figure how in the world they was ever going to get him to shore, even after the night was over.

"That night was the longest night on record. The minutes was hours, an' the hours was months, while the Portuguee clung there with only his head out o' the water, an' the fellers on the bank kept the fires an' their stunts goin'.

"WE SWUNG AROUND AGAINST A SHELVIN' ROCK."

"A little while before sunrise I stole back to camp to see what was doin'. As I crep' around a rock, I saw they had another fire there an' a gang of men was workin' at somethin'. Pretty soon I made out they was buildin' a scow. 'A fine chance there is o' sailin' this river in that scow,' I said to meself.

"All of a sudden the sun rose, an' it was day before ye knew it. I looked down the river, an' there was the Portuguee still holdin' fast. One look at that mad river an' I knew that no scow would stand a ghost of a show; but I said to meself if any one had to risk his life, I was the man, seein' I made the trouble in the first place. Mr. Carter, the chief engineer, was there over-seein' the work. I run up to him an' I says, 'If anybody is going in that boat, I am!' As soon as they seen me, they all made a rush for me, an' they 'd a' tore me to pieces in no time if Mr. Carter had n't druv 'em off. 'I dunno what your plan is,' I says to him, 'but I want to be in on it, no matter how dangerous the job.'

"'Good,' he says, 'I 'll take ye for the first volunteer. Jump into that boat.'

"An' then there was a wild stampede, an' the whole crowd rushed for'ard again. At first I thought they was comin' for me, but, would ye believe it, they was *all* volunteerin', an' Mr.

Carter had to drive 'em back with a pick-handle.

" 'I only need two more men,' he says. 'No quarrelin' now! Time is precious.'

"Al come pushin' up just then, and said he must be one o' them an' the Portuguee's brother would n't listen to stayin' behind. Then Mr. Douglass, the assistant engineer, said there must be at least two white men in the boat, an' he 'd go along, while Mr. Carter tended the cableway engine—"

"The cableway engine?" queried Jack.

"Yes," explained Doyle; "the scheme was to carry the scow out to the middle of the river on the cableway an' lower it into the water. At the stern of the boat there was two lines, one from each corner, fastened to the conveyin'-rope o' the cableway. Al had to tend one of them lines, an' I tended the other. Mr. Douglass stood at the bow watching for the boulders, an' telling us to let out on this line an' then on that. An' then he would signal to Mr. Carter to haul us to the right or to the left a bit, so as to get around this rock or that one. It was ticklish navigatin', I can tell yer! We had to go a good ways down-stream an' there was danger o' being swamped any minute. The waves looked pretty big out there. Twicet we nearly went

over. The last time was just as we reached the shipwrecked lad—an' his brother was trying to haul him into the scow. Al got so excited he dropped his line, an' we swung around against a shelvin' rock. But I stepped on the rope before much of it had paid out, an' Al soon pulled us around straight again.

"Well, we got the boy into the scow all right, but it come near being too late. He fainted dead away. His brother worked over him while the rest of us navigated the boat over to shore. But the poor chap did n't come to for over an hour.

"When we got back to land, I went straight to the boss an' give up my job.

" 'We need you, though,' he says, 'an' after this lesson I think you 'll be keepin' straight."

" 'I ain't going to touch another drop of liquor,' I says, 'but I don't expect you to believe it; an' as long as I 'm here you 'll be afraid o' me. You can use Al; he knows as much about this engine as I do.'

"So I packed out of there that very day an' took ship back to New York."

"And have n't you touched a drop since then?" asked Jack.

"Never a drop," declared Jim Doyle, proudly. "I see that face out in the water, an' I just lose all heart fer the stuff."

CHAPTER VI

LIGHT AND HEAT FROM SNOW

JACK stepped off the train at El Prado, and took a casual survey of his surroundings. It was here that the San Joaquin and Eastern left the main line and squirmed up into the very heart of the Sierras.

Suddenly Jack gave a gasp and darted up the platform.

"Perry!" he shouted, as he dashed through the crowd of men. "Perry!"

"Well, of all the good luck, Jack!" cried Perry, grasping his friend's hand. "Did you drop from the sky?"

Jack was so overwhelmed that he could hardly contain himself. "I have been looking for you for a whole year!" he explained.

"Have you, Jack? Well, I have been trying my best to find you, but all the letters I sent to Thunder River were returned to me. I even went there myself to find you, but Farmer Billups said you had run away, and threatened all

sorts of things if he ever found you again. What did you do it for, anyway?"

Then Jack recounted the history of his travels.

"And now I am on my way to Big Creek to get a job," he concluded. "Are you working up there?"

"No, I am just here on a visit. I have got to get back to Copper Center, Utah, by the end of the week. We have a wonderful piece of work there."

"'We'? Who 's 'we'?"

"Mr. Barto and I, and you too, Jack; you will have to come along with me."

"I 'd surely like to," declared Jack, "but you see, I have n't been able to lay aside much capital, and I 've got to earn my way. As a matter of fact, Jim Doyle loaned me the money to get to Big Creek; I 've got to pay it back just as soon as possible, and see if I can't find him a job, too."

"You don't mean to tell me you would try to get a job for that fellow!" ejaculated Perry.

"You don't know the man, Perry!" cried Jack. "The most wonderful change has come over him."

"It must be wonderful," declared Perry, "to have made anything of him."

"Yes it is, for he keeps sober now. He had an experience down in Brazil last summer that made a new man of him." Jack went on to tell about the affair on the Rio Pinto.

"Well, if he really has reformed, he 'll make a wonderful worker. Mr. Barto has often told me what a handy, all-around man he is. But, say," he broke off, "that must be our train," pointing to a freight-train with a couple of passenger-cars hitched on behind. "I think we had better jump on. Mr. Teal, a friend of Father's, is up at Big Creek, and is going to show me around. You come along with me.

"Oh, bother the clothes!" interrupted Perry, as Jack began to apologize about his appearance. "It is n't the outside, but the inside of a fellow that counts, and I am sure that is the way Mr. Teal will look at it, or my father would never have had anything to do with him. Now remember, you are my chum, and you are going along to Copper Center with me. We can fix it up with Jim Doyle. There is no reason why you cannot transfer your indebtedness to me." And, without giving Jack a chance to remonstrate, Perry changed the subject abruptly, and proceeded to talk about the gorgeous scenery that unfolded before them as the train started its winding course up the mountains.

"It 's a wonderful job, this! Mr. Barto was up here to see it last month and he said I must surely see it myself. Why, do you know, this railroad was built just to reach the spot. It is fifty-six miles long, and how much time do you suppose it took to build it?"

"About a year," ventured Jack.

"No; only one hundred and fifty-seven days!" declared Perry, triumphantly. "That 's less than three days to the mile, and you can see this is n't like track-laying in the prairies. They are pushing all the work at the same top speed."

"Why are they hurrying so?" inquired Jack.

"Well, I guess it is just the hustle of the West. They are doing big things in a big way, and I suppose—"

"The real reason," interrupted a voice behind them, "is that we want to save all the 'white coal' we can."

The boys faced about, to see a man leaning over the back of the seat.

"I hope you don't mind my entering into the conversation," he went on. "If I am not much mistaken, this is Perry Carpenter, is n't it?"

"Why, yes," stammered Perry, in surprise.

"I have n't seen you since you were a small

boy; but you have n't changed so very much. Now, I am Mr. Teal, your father's friend."

"Oh, Mr. Teal, I 'm mighty glad to see you. This is my old chum Jack. I 've just run across him and hauled him along with me."

"That 's right, Perry," Mr. Teal assured him very heartily. "There 's plenty of room for one more in my shack."

"It 's awfully good of you," said Jack. "I was really hunting up a job, but Perry insists on taking me with him to Copper Center."

"What was that you were saying about 'white coal'?" interrupted Perry.

"Oh, you know what we mean by white coal, don't you? It 's water; that 's what we call it here. In the East, electricity is made from coal; here it is made from water."

"What do you mean?"

"Why, in most of the Eastern plants the electric generators are driven by steam-engines, and the steam is made by burning coal in the boilers, so it is really the heat energy in the coal that makes the electric energy in the generator. Here we use the energy of falling water to drive the generators, so the water takes the place of coal. That 's why we call it white coal."

Power-house No. 2 Power-house No. 1

THE STORAGE LAKE, FED BY MOUNTAIN SNOWS, WHICH FURNISHES THE WATER-POWER TO CREATE THE MIGHTY ELECTRIC CURRENT.

Showing the two power-plants and the transmission lines leading from them.

THE TRANSMISSION LINES THAT CARRY THE CURRENT OVER THE MOUNTAINS.

"It seems funny to get electric light and heat from water, now, does n't it?" said Perry.

"Yes; and funnier still to get electric power and heat from snow."

"Snow! What do you mean by that?"

"Yes, snow. Where do you suppose Big Creek gets its water from? It is the most wonderful water-trap that Nature ever devised. The west winds, heavily laden with moisture from the Pacific Ocean, strike the lofty Kaiser Mountains, eleven thousand feet high, and condense—just as steam does on a cold window. The water drops as rain or snow. All winter long the snow gathers on the mountains, and then, when the warm spring rains come, it melts and swells Big Creek into a torrent. It is that big spring flood that we wanted to catch. That is why we were in such a hurry to finish the dams before spring. There is a natural basin up in the mountains, and, by building three dams, we made a reservoir four and a half miles long. Fortunately, they were finished in time, and the thousands of tons of white coal that the mountains were storing all last winter have been trapped in our reservoir. If we had n't completed it in time, we should have been

obliged to wait twelve months longer before starting up our electric plants. We expect to be delivering electricity in Los Angeles before the end of the year."

"Mighty quick work!" commented Perry.

"You will realize that better," declared Mr. Teal, "when you see what we have done. Why, do you know, at first it was planned to haul the materials and supplies from El Prado by team. Then I figured out what that would mean, and—would you believe it?—if we had a steady stream of ten-horse teams leaving El Prado every five minutes, it would take seven years to haul the stuff up to our plant. Naturally, we just *had* to build a railroad."

It was plain to see that Mr. Teal was proud of Big Creek, and he told the boys so many wonderful things about it that Jack, at least, expected he would see nothing less than a mighty Niagara pouring down the mountain-side.

"See, we are just rounding the bend into Big Creek Cañon!" exclaimed Mr. Teal. "There is Big Creek now!"

"Where?" cried both of the boys.

"Why, down there," said Mr. Teal.

"I don't see anything," protested Jack.

"Why, that stream down at the bottom of the cañon."

"What, that little brook!" sniffed Jack. "It does n't hold a candle to Thunder River."

"You must n't judge the power of a stream by its width or its depth either, but by its drop. Now there 's the Mississippi, biggest river in this country, one of the biggest in the world; but what good is it for power? They have built a dam across it at Keokuk,—mighty big dam, too, nearly a mile long,—but then the river drops only forty feet in twenty miles, so they can't get very much of a fall. They have to use enormous streams of water in mighty turbines fifteen feet in diameter, but all the power they are getting out of the plant is about one hundred and fifty thousand horse-power. Here we have a little stream with a drop of four thousand feet in six miles, and we are going to get eighty thousand horse-power out of it, with as much again when it is fully developed. You see, there is a big difference between a head of forty feet and one of four thousand. Why, the drop is so great that it would be risky to use it all at once, even if we could conveniently do so. For that reason we are using it in two stages of two thousand feet each. The water comes out of the reservoir and drops two thousand feet to the first plant, then it drops two thousand feet to the next. And, do you know what two

thousand feet means? If you took the three tallest buildings in the world—the Woolworth Building, the Metropolitan Tower, and the Singer Tower—and piled them one on top of the other, they would n't much more than reach from our first power-station to the level of the water in the reservoir."

"Jack has n't been to New York, Mr. Teal," interposed Perry. "He does n't know anything about real sky-scrapers."

"Is that so? Well then, I suppose he is more than astonished to learn that there *are* three buildings that would pile up over two thousand feet in the air."

"They must be pretty big," said Jack. "But you are telling me so many wonderful things that it will be hard to astonish me at all."

"Nevertheless, you will find two thousand feet is a big drop. I don't believe you have any idea what it means to drop water as far as that. There will be four streams, each spouting a jet six inches in diameter. That is not much when compared to the big flow through the Mississippi turbines, but those six-inch streams will be running at the rate of three hundred feet per second!"

"Is that so?" said Jack, in such a matter-of-fact tone that Mr. Teal was visibly disappointed.

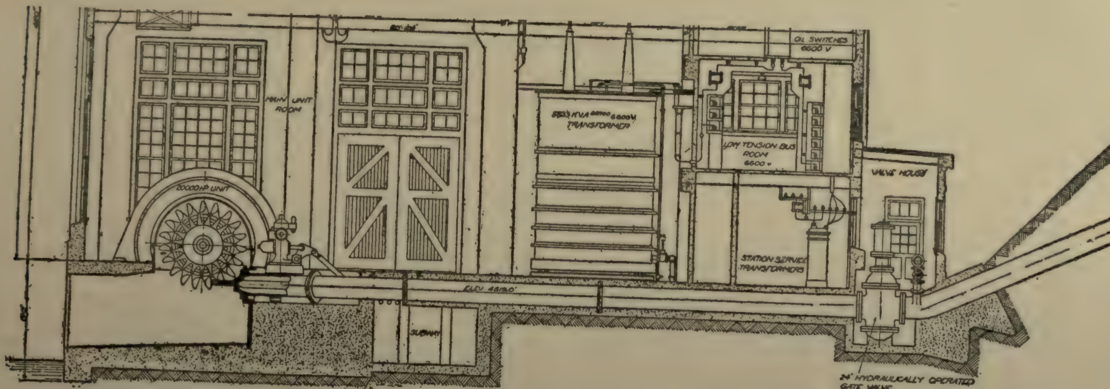


FIG. 6. SECTIONAL VIEW OF POWER-PLANT NO. 1, SHOWING A WATER-JET STRIKING AN IMPULSE-WHEEL.

"Pshaw! you don't know what that means, do you? Well, a train that makes sixty miles an hour is traveling eighty-eight feet per second. These streams would be going about three and a half times as fast, would n't they? Say, two hundred and ten miles per hour. You never saw anything travel as fast as that."

Jack was really impressed this time, and

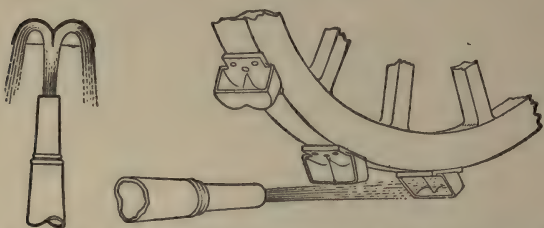


FIG. 7. HOW THE WATER-JET STRIKES THE TWIN BUCKETS OF THE IMPULSE-WHEEL.

showed it. "I should think it would tear any wheel to pieces!" he remarked.

"So it would—any common paddle-wheel, but these are impulse-wheels, and they have buckets so formed that the part the water first strikes is almost parallel to the jet; it is like this (see Fig. 7). The jet strikes the outer edge first, and splits in two because the buckets are double; then the bucket curves so smoothly that the water turns right back on itself and drops, al-

most without any velocity left, after giving up most of its velocity to the wheel. Yes; a water-jet running at two hundred and forty miles per hour is a rather powerful stream. The wheel-pits are lined with steel to keep the water from tearing them out. There are two impulse-wheels to each generator, one on each side, and these two wheels, driven by two six-inch jets, produce as much power as one of those great big fifteen-foot turbines at Keokuk. You see, these jets make up in speed for what they lack in volume. The Keokuk turbines make only fifty-seven turns per minute, while these fellows, nine feet in diameter, make three hundred and seventy-five.

"Here we are at Big Creek!" exclaimed Mr. Teal. "We 'll keep on to Camp Number Two. That is as far as the passengers can go. From there the track turns up the mountain-side. It rises about two thousand feet in a little over a mile of length. This is Camp Number Five."

"Have you as many camps as that?" questioned Perry.

"Why, yes; we have seven camps here without counting the camps along the transmission line that runs to Los Angeles. You don't realize how big this job is. It 's eight miles long, and we are working hard all along the line.

The long tunnel, for instance, is being attacked from ten different points."

"Tunnel? What do you need of a tunnel?"

"Why, we have two tunnels, one over four miles long. The water will flow from the reservoir through a tunnel three quarters of a mile long and twelve feet in diameter. Then it drops down about two thousand feet to power-house number one in a pair of steel pipe-lines, which branch into four pipes just before they enter the power-plant, so as to serve four impulse-wheels. From the power-house the water will be discharged into the creek. There is a dam across the creek here that will back up the water into a second tunnel four miles long, at the end of which there is another pipe-line that runs steeply down the side of the mountain to power-house number two, nearly two thousand feet below."

It was growing late when the boys reached the end of their journey. By the time they had finished their supper, it was nearly dark but work at Big Creek did not slacken. It was pressed day and night in order to make use of the valuable store of water that had been gathered in the reservoir far above them.

Jack and Perry caught their first view of the work by the glare of arc-lamps, which added a

Courtesy of The Scientific American.

THE HEAD OF WATER AT THE FIRST POWER-PLANT EQUALS THE COMBINED HEIGHT OF THE WOOLWORTH SINGER, AND METROPOLITAN TOWERS.

glamour to the situation and gave it a romantic appeal. Mr. Teal took the boys down into the long tunnel running from power-plant No. 1. Neither of them had ever seen any tunneling operations before, and despite the deafening roar of the drills as they pecked away at the tough granite, they found the work most fascinating, and insisted on staying until the holes had been bored, so as to watch the loading of the dynamite or "powder," as the men called it. Then they took their stand behind a wooden shelter with the firing-boss while the charge was set off. It was all very exciting, and almost like real war when the blast went off with a frightful bang and a powerful gust of wind, while a shower of small stones was hurled down the tunnel, glancing perilously near them. Then the choking fumes drove them out and sent them to bed with headaches.

Two days the boys spent at Big Creek, going over the whole work, from the reservoir filled with white coal, to the lower power-house, where the generators and impulse-wheels were being installed. What interested Jack most was the transmission line that was stretching out toward Los Angeles, two hundred and forty-one miles distant, and was well on its way there.

"Those lines will carry about one hundred and sixty thousand horse-power," Mr. Teal explained, "and the current will be sent over the wires with an electrical pressure of one hundred and fifty thousand volts."

"Why do you need such a high voltage?" asked Perry.

"Because the higher the voltage, the smaller the wire you need to use, and the cost of the wire amounts to something, I tell you. The lighter the wires, the farther apart the towers may be put, which is another important item; so in place of copper, the usual metal, we are using aluminum cable with a steel core to give it strength. There will be five million pounds of aluminum cable in the transmission line, and over three thousand steel towers. The wire is nine tenths of an inch in diameter. If we had used copper, it need not have been of so large a diameter, but it would have weighed more, and cost much more."

"What are those strings of knobs that the cables are fastened to?" Perry inquired.

"Why, those are the suspended-disk insulators. You know the old telegraph-poles have a little glass knob on a peg to insulate the wire from the pole. When wires were required to carry a higher voltage, the electricity had a

way of creeping over the surface of the insulator, in rainy weather, and leaking through to the pole. Then insulators were made with a set of 'petticoats.' The electricity could leak along the moist, dust-covered surface of the petticoat, but it could not so readily make its way along the clean, dust-free under-surface leading from the bottom of one petticoat to the top of the next. As the voltage grew higher, the insulators became larger and larger and had to have more and more petticoats, until finally they became too cumbersome to be supported on pegs. So the next development was to turn the insulator upside down and hang it from the cross-arm. That led to the type of insulator we are using, which, as you see, is made up of nine large disks of insulating material linked together. A hundred and fifty thousand volts is an enormous electrical pressure, and will make its way over a large insulating surface. That is why we have to have so many disks to keep it from leaking and making its way through to the towers."

"I don't see," said Jack, "how you can handle electricity of such high voltage in the power-plant if you have to have such careful insulation along the transmission lines."

"You don't suppose for a minute," laughed

Mr. Teal, "that the generators are going to turn out current at one hundred and fifty thousand volts! Of course we could not handle any such pressure in the plant, but the current that comes from the generators is under a pressure of only sixty-six hundred volts; then we put it through transformers that raise the pressure to one hundred and fifty thousand volts, merely to carry it over the long line to the substation at Los Angeles. There other transformers step down the pressure to seventy-two thousand and eighteen thousand volts before the current enters the plant and is distributed about the neighboring regions for light and power purposes."

"Two hundred and forty miles is a long way," mused Jack, as he gazed at the transmission line reaching out into the distance. "I guess I know more about distances than you do, Perry. I 've done a pile of walking in the past year."

"Yes," agreed Mr. Teal, "it is the longest express line on record. It is wonderful, when you stop and think about it. Here we take the power of a lonely mountain-stream and turn it into a mysterious, invisible, noiseless energy, and send it over cold, silent, motionless wires; over mountains, across valleys, through forests

and desert wastes to a distant city, there to turn night into day, to drive trolley-cars and powerful machinery, to cook food, and to provide a thousand and one comforts in the home."

CHAPTER VI

FEEDING A RIVER WITH PUMPS

"WASN'T it wonderful?" remarked Jack, when the boys were on their way out of Big Creek Cañon.

"Yes," admitted Perry. "I'm afraid you won't be much impressed by the job *we* are on, and yet it is one of the queerest engineering stunts you ever heard of."

"Say, you haven't told me anything about that! I've been seeing so much here that I forgot there was anything else worth talking about. What's queer about your job?"

"Well, it's like this," explained Perry. "We are building a pumping-plant to pump water out of a lake. That water goes through a power-plant that makes electricity, and the electricity drives our pumps."

"Hold on, now!" cried Jack. "That sounds like perpetual motion."

Perry grinned. "Yes, that is what they all say when they first hear about it. I thought it was perpetual motion, myself."

"But," said Jack, somewhat perplexed, "you said that you pumped the water to make the electricity to drive the pumps that pumped the water, did n't you?"

"Yes."

"Well, that is like running around in a circle. You don't get anywhere. I don't see how you start in. You have to have the electricity before you can work the pumps; and you have to have the water before you can get the electricity; and you have to work the pumps before you can get the water. If that is what you are trying to do, it can't be done; and even if it could be done, what 's the use of it all?"

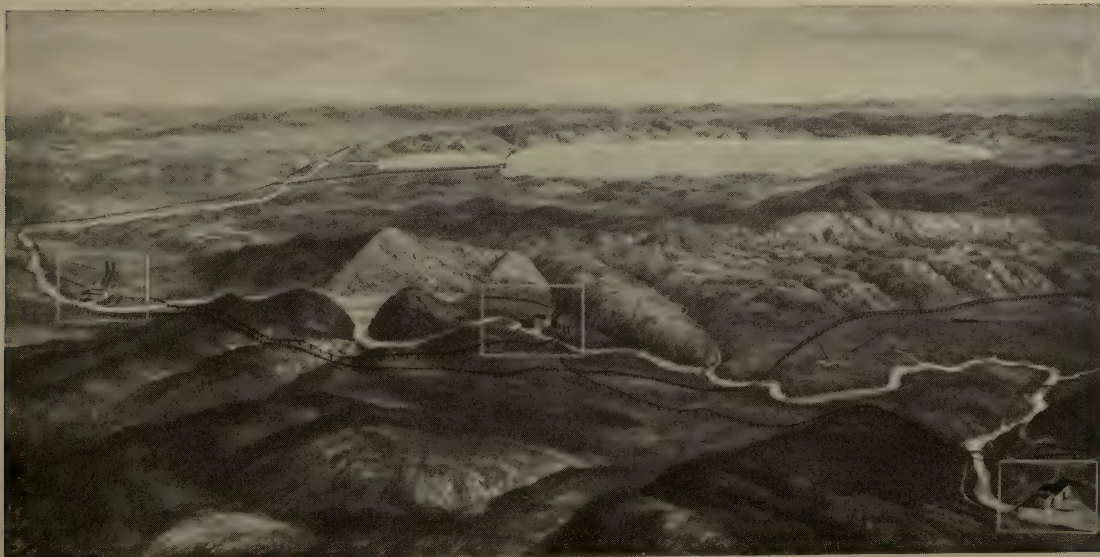
Perry burst out laughing. "Jack," he said, "that is almost exactly what I said to Mr. Barto."

"But is n't it true?"

"No; the thing will work, and it will make a whole lot of useful power. It 's like this: Copper River, when it is high, overflows into a big lake. Oh, it is very much bigger than the reservoir at Big Creek. Why, it 's twenty-five miles long and fully eight miles wide. So, you see, it will store an immense amount of water. Now when a dry spell comes on, they are going to swell the river by pumping the water out of this lake back into the stream, and to do this

they may have to raise the water as much as twenty feet. But about fifty miles away, at the Torrent power-plant, it drops over five hundred feet, so that it makes a great deal more power there than is needed to drive our pumps. After that, the water goes through two more power-plants, dropping, altogether, five or six hundred feet more before it reaches Great Salt Lake. So you see, by raising the water only twenty feet we get a drop of over a thousand. As a matter of fact, twenty feet is the most we 'll have to raise the water. That will be near the end of the season, when the water in the lake will be very low. Ten feet will be near the average lift. But the drop at the three power-stations will be seven hundred and fifty feet altogether, so the water will do seventy-five times as much work for us as we do in lifting it into the river. Mr. Barto says that, even allowing for loss of power in the machinery, the water should give back forty horse-power in our transmission lines for each horse-power we take out of them to drive the pumps."

"But, I don't see," persisted Jack, "why you have to pump the water out. Why don't you dig a canal to some point farther down the river, so that the water can run out without pumping it?"



BIRD'S-EYE VIEW OF COPPER LAKE AND THE THREE POWER-PLANTS (IN SQUARES) THAT IT FEEDS.

"You just wait and you will see why," answered Perry. And when the boys finally reached Copper Center, a couple of days later, and Jack sized up the situation with his own eyes, the reason was very clear. Right there Copper River was a sluggish stream and ran through a broad, flat plain for miles and miles without much, if any, drop. Copper Lake was about on a level with the river; in fact, the lower end of the lake was a great swamp six miles long and fully as many miles wide. A sand bar separated the swamp from the main lake, and on this sand-bar the pumping-plant was to be built. A canal was being dredged through the swamp to the river, and a system of dykes was being built to divert the floods from the river past the sand-bar and into the main lake. The pumps could draw water out of the main lake until it was lowered twenty feet or more below the level of the swamp outside. To do this without pumps, it would have been necessary to dig a deep canal through the mud and swamp-land and carry it through the flat plain for a distance of thirty or forty miles before the river dropped low enough to receive it.

Mr. Barto himself came to the station in his automobile to meet the boys. He was as pleased as Perry had been to see Jack again,

and he took pains to explain everything to him.

"I suppose those pumps will have to be pretty large, won't they?" asked Jack.

"Well, I should say so!" replied Mr. Barto. "They will be the biggest centrifugal pumps in the world. There will be five of them, and they will pump a river of water. Each one of them will lift three hundred cubic feet per second, that is, fifteen hundred cubic feet altogether."

"Let me see," said Perry; "they said that Big Creek ran about 300 cubic feet per second on the average."

"Well," said Mr. Barto, "that means these pumps will deliver five times as much as Big Creek. You can see that they will be a material help to Copper River during dry seasons."

Mr. Barto's task at Copper Lake was to lay the foundation for the big pumps. He was building an enormous caisson. To be exact, it was one hundred and forty and a half feet long, by sixty-two feet wide, and it was a mass of timbers. As Jack remarked when he arrived, it looked more like a lumber-camp than a piece of foundation work. Fifty car-loads of timber were being put into the caisson, and it was all divided up into sections by the cross-bracing. Some of the sections were floored and walled off with planking to form big hoppers, which

were filled with sand. There were four hundred tons of sand in these hoppers just to weight the caisson and force it down into the ground.

"Are you going to have one big working chamber under the whole caisson?" asked Jack.

"No; we won't have any working chambers. This caisson is going to be sunk without using compressed air," announced Mr. Barto.

"But how are you going to keep the water out?"

"We are *not* going to," replied Mr. Barto. "We don't care if it does flow in. In fact, we want the water in, and may actually have to pump it in."

"But how can the men dig out the sand if the caisson is full of water?" questioned Jack.

"We are not going to use men, but machines. We are going to dredge out the sand with clamshell buckets. It 's going to be a hard job putting that caisson down evenly. If one end gets ahead of the other, it is going to put an awful strain on the caisson, and it may be hard to straighten the big box up again; and so we 'll have to watch it carefully and keep it straight by dredging a little more out of this pocket, and then that, so as to keep the caisson from sluing off sideways."

"What did you mean by saying that we might have to pump water into the caisson?" asked Perry.

"Well now, that is pretty much of a trade secret," answered Mr. Barto, "but it is one you ought to know. The soil we are going through is very fine, and water does not flow through it as easily as it would through gravel or coarse sand for instance. Now, when we dredge out the mud from inside the caisson, a great deal of water will be taken out by the buckets with the mud, and, if the surrounding water does not flow in fast enough, there may be quite a difference of level between the water inside the caisson and the lake outside. That will put a heavy pressure on the caisson. The mud and fine sand may be pressed so tightly against the caisson walls that the caisson will stick and will not go down. Then the only thing to do is to pump water into it so as to relieve the pressure. We may even have to raise the water inside the caisson to a higher level than the lake, so that it will flow out under the cutting edges of the caisson and work up outside, freeing it from the mud that is holding it. Then there is another difficulty; the material is so fine that it is easily carried by flowing water. If the level inside is low, there may be an inward flow under

the cutting edges that will bring in a lot of fine sand or mud. If this is n't watched carefully, a big cavity may be washed out under a corner of the caisson, and then suddenly the caisson might tip into it, and we 'd have a tremendous job trying to straighten it again. You see, we can do a lot of juggling by raising or lowering the water-level in the caisson; at the same time we must keep on the watch to prevent the caisson from playing tricks on us."

"What are you going to do when you strike rock?" asked Jack.

"Strike rock? Why, there is n't a rock within two hundred feet of where we want to go."

"But are n't you going to build the foundations on rock?"

"Oh, no; these are to be pile foundations," replied Mr. Barto. "After we get the caisson down forty or forty-five feet, where we want it, we 'll drive piles into the ground through the pockets. Fortunately, piles are to be had very cheap in this country. We are going to use seventy-foot piles, and drive them about forty-five feet into the ground. We 'll let them stick up out of water so that we can see just where they are when we lay our concrete around them. When the piles have been driven, we expect to

cover the bottom with a layer of concrete about eight feet thick. Then we 'll pump out the caisson and plug up all the leaks. After that we shall proceed to build the walls of the pumping-plant inside the caisson and make the big pits for the pumps. It is a novel piece of work and the biggest caisson ever built. It does n't look like so much out here in the open, but if we had it in New York City, for instance, it would be big enough to choke lower Broadway and would be more than half a city block in length, while the top of it would reach above the third-story windows. But I forgot; you have n't seen New York, have you? Well, you will before long. As soon as we get this caisson all the way down, I have got to get back home, and you are coming with me. I 'll show you the most wonderful engineering city in the world."

"What, me?" cried Jack, in astonishment.

CHAPTER VII

BESIEGED BY A RIVER OF ICE

IT was late in February by the time the work at Copper Center had proceeded far enough to permit Mr. Barto to leave for New York. Then, as there appeared to be no further trouble in store, Mr. Barto, with Perry and Jack, took the east-bound express.

"I am very anxious to inspect a railroad bridge that our company is working on," announced Mr. Barto, "a bridge across the Missouri River, right on our way, so we 'll stop off and look at it. It was built over ten years ago. Now a new bridge is being built that is to use a part of the old one, and the transfer of the old to the new is not going to take more than a minute or two."

Jack and Perry both sensed something interesting, and began plying him with questions.

"I will tell you the whole story," said Mr. Barto. "When it was first decided to build this bridge, there was n't enough money to be had to erect a first-class structure throughout.

It must have been a man with a very wise head that proposed the scheme adopted. Of course, any bridge across the Missouri at that point would have to have a draw span to let boats through, and because the river-bottom is constantly shifting, this span ought to be very wide. So this man, whoever he was, said: 'Our road is going to grow, so we 'll put most of our money into a swing span, and make the swing span strong enough and big enough to carry all the traffic that will probably go across it for many a year to come. Then we 'll put up trestle approaches and short girder spans resting on piers of piles, to connect this swing span with the shores—

"No, that was n't so wonderfully wise," agreed Mr. Barto, interrupting a remark to that effect by Perry. "Lots of people plan for the future like that, but this man had a longer head than most wise men. 'Now this is a temporary structure,' said the man. 'It will last seven years, maybe eight. That is n't a very long time; then what shall we do? How are we going to build our new bridge without tying up all the traffic across the river?' How do you suppose he did it?"

Jack shook his head. "I never could guess."

"Give it up. What 's the answer?" said Perry.

"His answer was just as simple as the scheme was clever. 'The only part of the first bridge that we want to save,' he said, 'is the swing span. If we build the second bridge at a slight angle with the first, so that two cross like a long narrow X, with the center of the X at the swing span, traffic can flow over the first bridge while the second is building, and then when all is ready it will be a matter of not more than a minute or so to turn the swing span on its pivot and line it up with the new bridge.' "

"That *is* simple, is n't it?" cried Perry.

"And clever, too," added Jack.

"Yes," continued Mr. Barto, "and that fellow must have been as thorough as he was forehanded. He made such a solid structure of the temporary part of the bridge that, although it was supposed to last only seven or eight years, it is still in good condition, and is just beginning to show signs of giving out. Probably it will have given service for close to twelve years before the new bridge is finally completed."

All this was very interesting history, but the boys did n't anticipate seeing anything unusual in the construction. However, Mr. Barto ex-

plained that what interested him most was the manner of sinking the pier for the new swing span.

"I told you," he said, "that they paid particular attention to the swing span of the old bridge. Well, it was a big span, 520 feet long, as long as two avenue blocks of the kind we have in New York; the longest swing span that had ever been built up to that time. It was planned to build a set of fixed spans for the new bridge, but the old Missouri has a mind of its own. It is such an unreliable river that the channel shifts 'overnight,' as they say, and you might wake up some fine morning to find that the channel had moved out from under the swing span and shifted to the fixed part of the bridge. So now they are going to build a new swing span, just as big as the first, and our company is putting down the foundation for this span to swing on; that will allow the river over a thousand feet in which to shift its channel without tying up shipping.

"The foundation for this pier is being put down by means of a big caisson, something like our caisson here; that is, the sand is being dredged out from inside the caisson as it was from our caisson, but in the Missouri work the

caisson has to go down about one hundred and fifteen feet."

"Whew! That 's pretty deep," cried Perry. "Won't they have lots of trouble with it?"

"Oh, no; the pivot pier of the first bridge was put down in the same way."

Perry and Jack arrived at the scene of the bridge expecting to see a massive caisson like that at Copper Center. Instead, they found a cylinder of steel some forty feet in diameter. Inside this was a second cylinder, twenty feet in diameter, which at the bottom flared out to meet the edge of the forty-foot cylinder, and thus made a cutting edge. The two cylinders were strongly braced together, and the space between them was filled with concrete. This made a wall ten feet thick, and also made the caisson heavy enough to sink when the sand and mud were dredged out from inside the twenty-foot shell.

The only way to get out to the caisson was by means of a rowboat.

"We are rather short of boats this morning," explained Mr. Davidson, the engineer in charge. "A couple of them drifted away from us last night because one of our stupid men did not know how to tie them fast, and we have n't

got them back yet. I shall have to send this boat back because it is needed on some of the other piers. The men at the caisson have a boat that we can get to shore with when we are ready.''

Before the day was over, Mr. Davidson had occasion to regret, sincerely, that he had sent that boat back.

The day was an unusually warm one for the first of March. No one seemed to notice the heavy black clouds that, in the early afternoon, sprang up in the west, until, suddenly, the sun was obscured and a gale of wind arose.

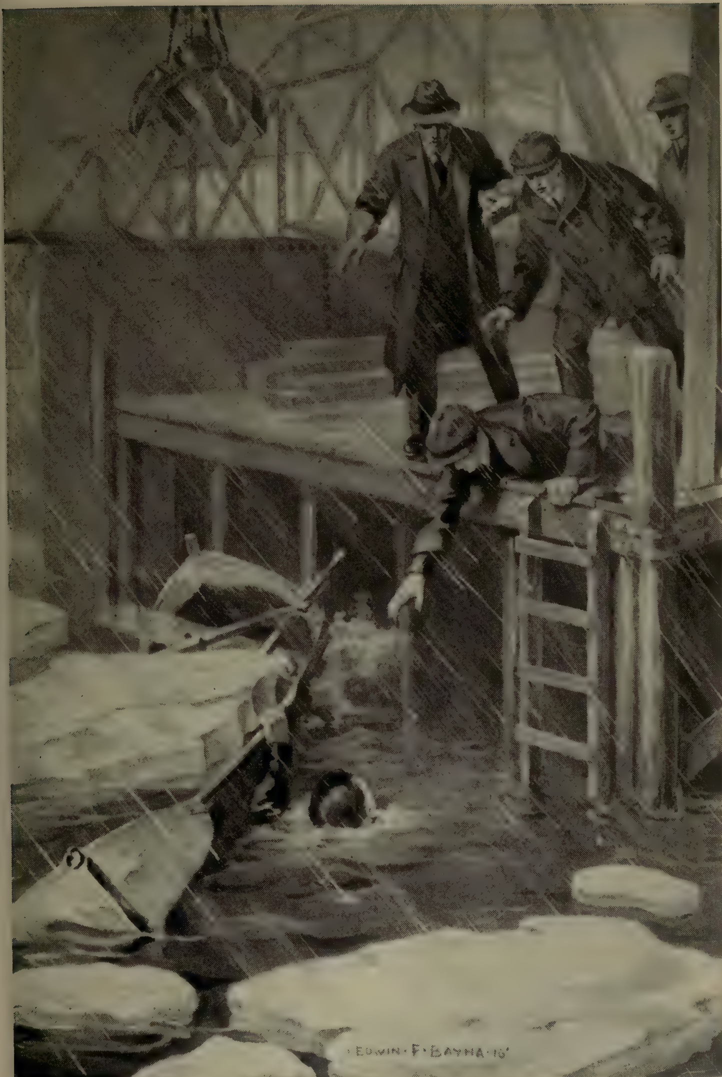
''Look there, Davidson!'' cried Mr. Barto. ''We had better get away from here. This looks like a pretty bad shower for so early in the season.''

''Here, Mike,'' called Mr. Davidson, ''the boat! We want to get ashore ahead of that storm.''

''Can't be done,'' said Mike. ''Look there!''

A sheet of rain was sweeping down the river upon them. ''Guess you are right, Mike. We'll take to cover here until the shower is over.''

They had barely reached the shelter of the workmen's shanty when the storm broke. It was a veritable cloud-burst. The lightning and



THE ICE CRUSHED THE BOAT AGAINST THE PILES LIKE AN EGG-SHELL.

thunder were almost incessant, and the pouring water was driven by a hurricane. For an hour the storm continued without a sign of abating.

"Looks as if we would be marooned here all the afternoon," growled Mr. Davidson. "Why, I never saw it rain harder in my life. Suppose we try the boat, anyway; I don't mind a wetting."

"I am not so anxious as that to get ashore," returned Mr. Barto.

Another hour passed. The river was rising rapidly. "Seems to be a lot of ice coming down, Mr. Davidson," remarked Mike.

"You 're right," said Mr. Davidson. "We can't wait any longer. The warm weather and this storm have set free a field of ice. We had better hurry off while we can."

Mike went down the ladder and jumped into the boat, while the four others made ready to follow him. The wind had abated somewhat, but the river was swirling madly past the caisson, bearing enormous slabs of ice that crashed against the light trestlework on which the working platform was supported, and threatened to smash it.

Just as Mike stepped into the boat an unusually large chunk of ice bore down upon it.

"Look out!" yelled Mr. Davidson.

Mike turned, but too late to save the boat. The ice struck it and crushed it against the piles like an egg-shell. Mike was thrown into the water, but he managed to reach the ladder and climb up to the working platform.

"Guess you 'll stay out here a while longer, Mr. Davidson," he remarked. "Me for the engine-room to get dry."

"Why, this is serious!" exclaimed Mr. Barto. "Look at all that ice bearing down upon us. Is there no other boat around?"

"No," replied Mr. Davidson. "All we can do is to signal to shore for help."

"How in the world are you going to do it?"

The derrick engineer stepped out with a megaphone and began hallooing, but his voice did not carry very far. The storm and the river were making too much noise, and, besides, every one had taken shelter from the rain.

After an interminable wait, a man in oilskins sauntered out on the old bridge where he was within hailing distance, to see what was wanted.

"A boat!" cried Mr. Davidson, excitedly. "A boat, that is what we want. Ours is smashed."

"It is too late now," interrupted Mr. Barto. "No rowboat could navigate this ice-strewn water. Look at that solid field of ice. What we need is a tug. Is n't there one around here?"

"No, not within fifty miles."

"Why, how did you get this barge-load of stone and concrete down here?"

"In the usual primitive way used hereabouts," explained Mr. Davidson. "We hauled the barge up the river and floated it down-stream to the caisson. A tug is a curiosity in this region."

A few minutes later, a rowboat put out from shore. The two engineers and the two boys were not the only ones who watched its progress. There was an interested group on shore, and the workmen on the caisson, too, realized that this was their only chance of getting away before the ice cut off their escape completely.

For a time the rowers made good progress, dodging the ice cakes very skilfully; but they could not play that game forever. Before long the boat was caught by a field of ice and was borne helplessly down-stream.

"There goes our last hope," declared Mr. Davidson. "If Donovan had only known some-

thing about sailors' knots, we would not have lost those boats last night, and we would n't be in this predicament now. Heaven only knows when we will get away from here."

It had stopped raining, but things did not look any brighter. The ice was running by in an almost solid field, banging against the caisson, piling up against the light trestlework, crunching and grinding, and making a most deafening noise. It was rather terrifying to the boys, although neither would admit any fear.

"Looks to me as if the storm was over," exclaimed Perry, hopefully. "I guess the river will quiet down now."

"It has taken more than this storm," growled Mr. Davidson, "to raise the river so high. There must have been other rains farther upstream; besides, this sudden thaw must have set free a lot of water that has been held in storage all winter in the form of snow and frost. But it is n't the water that concerns us. It 's the ice. As long as it runs by, we 'll have to stay here."

Night fell, and the stars came out to look upon the prisoners on the little island in the river of ice. As for the prisoners, they merely gazed helplessly, speechless and fascinated by the

sight of the stream of grinding masses that bore down upon them and crashed against the piles beneath them. All hope of immediate rescue had been abandoned. They had begun to plan for a long siege. The derrick engineer and his assistant each had a full dinner-pail, which they generously offered to share with the rest. By common consent it was agreed to fast that night and save the food for the morning.

In time Jack and Perry grew drowsy, and Mr. Barto sent them into the shack, where they soon fell asleep despite the jar and thunder of the ice.

About two A.M., Mr. Barto aroused them and hurried them over to the caisson.

"It is no longer safe here on this working platform," he explained. "The wind has been driving some enormous masses of ice toward this side of the river and they threaten to smash our piles to pieces."

The men huddled together on a narrow platform built across the inner and outer shells of the caisson. The sky was overcast now, and only a lantern did its feeble best to dispel the gloom. But the crunching, grinding thunder of the ice, punctuated by powerful crashes that fairly made the timbers tremble beneath them, apprised them that the onslaught against their

stronghold was still on. And so the endless night dragged along.

Then day broke; but it brought no new hope, for the weather was milder than ever. There seemed not the slightest chance of a freeze, nor the vaguest possibility that the supply of floating ice would ever be exhausted. The working platform was still standing, despite the attacks it had endured all night, and now that it was light the men ventured back upon it again.

Hunger was beginning to gnaw on the besieged garrison, but, by common consent the fast was continued a little longer and the store of food saved for a later date.

Some men came out upon the old bridge and tried to megaphone over to the caisson, but it was well-nigh impossible to hear anything above the noise of the ice.

"The only man with any sense in the whole gang," grumbled Mr. Davidson, "is down on his back with a fever. We can't expect any intelligent action from that crowd."

"I have been watching this ice rather closely for the past hour," said Mr. Barto, "and I have noticed a thing or two that looks rather promising. There must be a sand-bar over there. Do you see how the ice seems to pile up? It is n't so very far from there to that

pier," pointing to the old bridge. "Once, a few minutes ago, there was a jam of ice all the way across for about a minute, and then it broke away again. Now there is just the chance that a jam might form there long enough to clear the water around us and let us get away. There, see that!"

An unusually large ice-floe ran aground on the sand-bar in such a way that the following blocks piled upon it instead of pushing against it. A buttress of ice was soon formed that stood up stanchly against the current.

Time after time large masses of ice would form a momentary chain all the way across from the bridge pier to the ice buttress, but the chain always broke. It was tantalizing to see the ice keep building up there, only to give way almost as soon as formed. Nevertheless, the sand bar held out some hope, and the watchers on the caisson were cheered to observe that the men on the bridge had hauled over a couple of boats and had them suspended ready to be launched the instant that opportunity offered.

It was well along in the afternoon when an unusually large sheet of ice came sailing down the river. It reached across the entire span between the ice buttress and bridge pier. Best of all, when it struck, the forward end tilted up-

ward, while the rear dipped under the water making a shelving beach on which the following masses of ice instantly piled.

"It 's a jam," cried every one, excitedly. "Now if it will only hold ten minutes."

The men on the bridge pier dropped the boats into the river and paid out the lines they were attached to, letting them float down toward the caisson. In another minute the boats had reached the caisson, and it did not take long for every one to pile in.

Now they faced real peril. They had to be drawn up-stream, through the lane of comparatively clear water, right up toward that towering ice jam. If that broke nothing could save them.

Steadily the ropes were hauled in by eager hands, while the men at the oars worked frantically. It was a desperate chance. Before them rose the ice barrier, now fifteen feet high, but looking five times as high to the men in the boat. How long could the ice stand the strain? Would not the growing mass force the buttress off the sand-bar and let down thousands of tons of ice upon them? It took only a few minutes to cover the space of open water, and once the bridge pier was reached, the men scrambled out and clambered up with the agil-

ity of monkeys; but scarcely had they reached safety when, with a report like that of a cannon, the ice jam broke, and the big blocks hurled themselves with redoubled violence against the stanch caisson.

"Lunch is served, Dan," shouted the derrick engineer to his assistant, and the two sat down then and there on the pier, to gobble greedily the contents of their precious dinner-pails that had been guarded so carefully through all the trying hours. At the word the rest of the men broke and ran for the nearest restaurant. It was a cheap little chop-house, ill provided for the demands thus suddenly imposed upon it. In half an hour it had been swept as clean of food as if it had been visited by a plague of locusts.

CHAPTER VIII

RIGHTING A TILTED GRAIN ELEVATOR

"I MAY be all twisted in geography," declared Perry, "but I cannot for the life of me make out why we have boarded a north-bound train to go to New York."

"We *are* headed a few points off our course," admitted Mr. Barto. "In fact, the route we are going to take may be a thousand miles longer, but there is something up in Canada I want to see."

"What is it?" chorused Perry and Jack, eagerly.

"A grain elevator," announced Mr. Barto, with a peculiar smile.

"Is that all?" sniffed Perry, plainly disappointed. "We have seen lots of them, have n't we, Jack?"

"But have you ever seen the inside of one?" asked Mr. Barto.

"N-no," reluctantly admitted Perry. "I know how they work, though." He had seen many of those big tower-like structures with massive grain bins alongside. Mr. Barto, him-

self, had explained how the grain is emptied out of the cars by power shovels—shovels that can be easily pushed into the car by hand and buried in the grain, but which are automatically drawn back by power machinery as soon as the hand releases them. He had been told all about the course of the grain from the pits under the cars to the receiving hopper at the top of the workhouse, whence it is fed to the weighing hopper and then delivered through a system of spouts either to the working bins in the workhouse or to conveyers that carry it to the storage bins in the bin-house. Yes, Perry felt that he knew all about grain elevators. "Is it the biggest elevator in the world?" he said.

"Oh, no," answered Mr. Barto; "and yet it is big enough. The storage bins are ninety feet high. There are sixty-five of them, each fourteen feet four inches in diameter, and, because they are cylindrical, there are diamond-shaped spaces between them, which are also used to store grain. These are called 'interstice' bins. Altogether the bin-house will store a million bushels of grain."

"Whew! That 's a lot!" exclaimed Jack.

"Quite a bit," agreed Mr. Barto. "It takes about eighty thousand acres to grow that much wheat; but that is n't such a very large part of

the wheat grown in this part of the world, to say nothing of the corn, rye, maize, and so forth."

"But why are we going up into Canada to see a grain elevator when there are lots of them right here in the United States?"

"Because I happen to have a special interest in this particular elevator," replied Mr. Barto. "It is built of concrete, you know. The walls are six inches thick, and it is pretty heavy—about twenty thousand tons for the bin-house alone. It rests on a floating foundation—"

"Floating?" echoed Perry; "a new kind, is n't it?"

"Not at all," replied Mr. Barto, "particularly out there. The ground is a good stiff clay, and it is customary to put down a big slab of concrete, a 'mat,' as they call it, that distributes the weight over a broad area. That 's the kind of a foundation that was put down for this elevator, and it was expected that the clay would give a little and let the building settle a bit. And so, when the bins were first filled, care was taken to distribute the grain evenly in all of them, so that the building would settle evenly. Just as was expected, when the bins were nearly full of grain, the structure began to sink, and it went down about a foot in an

THE TILTED GRAIN ELEVATOR, SEEN FROM THE EAST.

THE GRAIN ELEVATOR, SEEN FROM THE WEST.

hour. Then the unexpected happened. Instead of sinking evenly, the building began to tip toward the west. Slowly, very slowly, it careened. The men were helpless to stop it. Twenty thousand tons is quite a mass to stop, no matter how slowly it is moving. I tell you, a man feels mighty small when he has to contend with such giant masses, even if they are made by him.

"All night long the sinking continued. A little after midnight the bins were leaning over so far that parts of the cupola, or frame structure that covered the top of the battery of bins, slid off and fell to the ground with a mighty crash. But still the settling continued. Strange to say, it was only the battery of bins that settled. The workhouse, which was carried on a separate concrete mat, was not harmed. If that had gone, with all the costly machinery it contained, the loss would have been great indeed. At the end of twenty-four hours the mammoth structure came to a halt at last. The bins were leaning over at an angle of nearly twenty-seven degrees. The foundation on the west side had sunk twenty-nine feet, while the eastern edge of the foundation had been lifted up about five feet above the normal level.

"The first thing to do was to take care of the

grain, and so they dug holes through the concrete walls and placed a conveyer under the holes to catch the grain and carry it to a pit at one side, from which it was elevated and loaded into cars. A conveyer, you know, is a belt with buckets on it that scoop up the grain and carry it along. After the bins on the west side had been tapped, holes were cut through to the next row, and so on until all the bins had been tapped. The grain that was below ground level was taken out by the regular conveyers in the basement of the bin-house which ran to a pit, and then an elevator carried the grain up to the conveyer that had been rigged up outside of the bin-house.

"It was a risky business, unloading the bin-house, because of the fear of upsetting the balance of the structure and starting it to tipping in some other direction."

"But what made the bins begin to topple over?" asked Perry.

"Something away down in the ground, forty feet below the surface," answered Mr. Barto.

"It was water, was n't it?" queried Jack.

"Well, that had a good deal to do with the settling, but not the tipping. Borings showed that the ground was made mostly of blue clay forty feet deep, and below that there was a

layer of soft white clay with boulders in it; then came a layer of broken limestone that lay on bedrock fifty-five feet below the surface. But here is the queer part of it; everywhere else around there the bedrock lay fairly flat, but right under the east side of the bin-house there was a ridge of boulders sticking up about five feet above the rest of the rock, and into the white clay."

"But what did that have to do with it?"

"Simply this," explained Mr. Barto. "As there was less depth of clay there, the ground could not yield as much over the ridge of boulders as the ground at the other side, and that started the building tipping. The more it tipped the greater became the weight on the west side and the less on the east side. The clay just flowed out from under the bin-house and threw up a big earth wave about five feet high. Work was started just as soon as possible on new foundations for the workhouse, because nobody knew when that might start to tip, too. The job of putting down the foundations to rock was undertaken by the Canadian branch of our company, and that telegram I received yesterday was an order to go and consult with the engineer in charge of the work and see how things were progressing."

When the party arrived at its destination a couple of days later, the boys were astonished at the sight. They had been told that the bins were tilted to an angle of twenty-seven degrees from the vertical, and yet they were awe-struck at the spectacle before them. A tree or a pole could lean over at such an angle without impressing them particularly, but to see an enormous structure like this balanced on one edge was startling indeed. It looked as if it might topple over any moment.

Mr. Abbe, a young assistant engineer, took the boys around for a general survey, while Mr. Barto spent his time with the chief engineer.

"It is certainly going to be an awful job straightening up that bin-house," remarked Jack.

"Yes," said Mr. Abbe, "but it was a much more perilous job putting in the foundations under the workhouse. We started doing that several months ago, and they are nearly finished now. It was ticklish work, because we did not know when the building might tip over and crush the workmen in the wells they were digging. There was such a lot of water, and we had to work in awfully cramped quarters."

"But why were you digging wells there?" asked Jack.

"Why," explained Mr. Abbe, "we had to dig down to rock and then build up concrete piers from the rock up to the workhouse."

Mr. Abbe took the boys into the workhouse and showed them a wire hanging from the top of the building. Attached to the lower end of the wire was a heavy weight submerged in a tank of water, and there was an electric coil in the tank to keep the water from freezing in cold weather.

"See that?" said Mr. Abbe. "That 's a pendulum. We keep the pendulum bob in water so that the wind cannot disturb it. Every day we measure the position of that pendulum to see whether the building is tipping."

"When are you going to start righting the bin-house?" asked Perry.

"We have already started. In fact, the bin-house is moving now." Perry and Jack both gazed at the leaning building. It seemed as motionless as the Sphinx.

"I don't see it move," Jack declared.

"Maybe you don't," said Mr. Abbe, "but she is moving just the same. Yesterday she moved about three inches. To-day she is doing better."

"Have they got jacks under the lower edge?" inquired Perry.

"Oh, no," said Mr. Abbe; "we are not trying to lift the low side. We are simply letting down the high side."

"But then your bin-house is going to be on a lower level than before," protested Jack.

"Yes, but what of it? It is simpler to rearrange the conveyers and elevators than to try to raise twenty thousand tons. And I assure you you would realize how heavy the building is if you had seen the condition of the clay under it. All the water had been squeezed out of the white clay, and it was so hard that we actually had to use a pick on it."

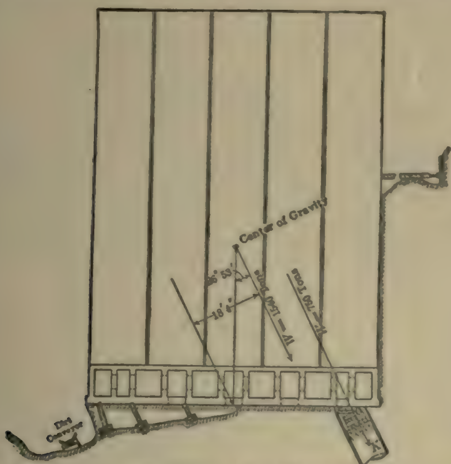
Mr. Abbe showed the boys the pushers against the west side of the bin-house and the jacks with which the men were slowly pushing the building over. Then he took them to the east side and into the tunnels that had been dug under the upturned mat of the bin-house.

"You see," he explained, "we dare not dig away too much earth at a time, so we run drifts, or tunnels, under the mat, leaving a thick wall of earth between the drifts. These earth walls are like wedges under the bins, but they are slowly crushed out as the bins are righted, and all the time serve to keep the bins from moving too fast."

Mr. Barto spent a month watching the prog-

ress of the work, and all that time the bin-house was slowly being brought to an upright position, moving only a few inches per day.

Just before Mr. Barto had to leave, a change



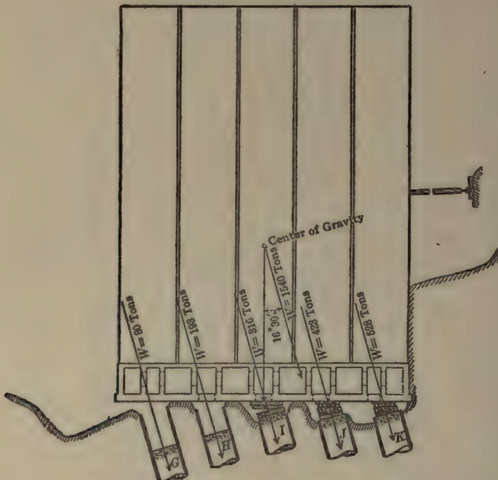
Courtesy of the American Society of Civil Engineers.
FIG. 8. TILTING THE BATTERY OF BINS ON PIER K AS A FULCRUM.

was made in the plans. If the bin-house were righted by merely dropping the high side, it would lie far below the level of the surrounding prairie, and it was feared that it would be difficult to keep the grain dry in the lower part of the bins. It was decided that the bin-house would have to be raised to a higher level.

"But how are they going to raise such a

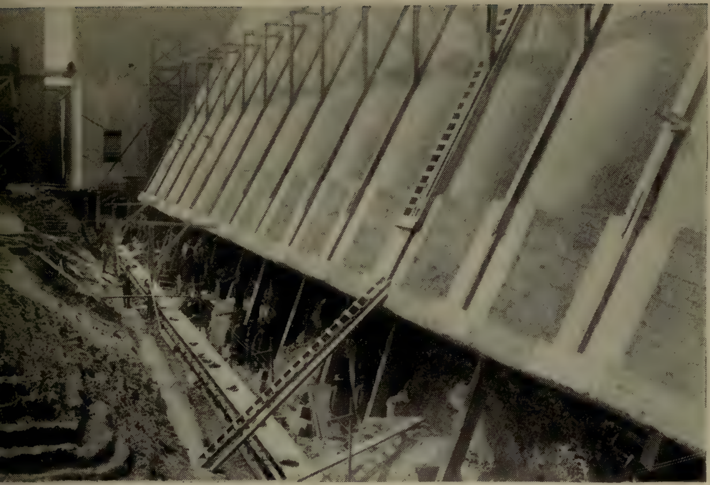
heavy building?" asked Jack, when he heard of the change of plans.

"They are going to let one half of the build-



Courtesy of the American Society of Civil Engineers.
FIG. 9. ROCKING THE BINS ON PIER I AS A FULCRUM.

ing help raise the other half," said Mr. Barto, with a smile, as he watched the puzzled expression of the boys. "I mean," he explained, "they are going to rock the building. The piers under the middle of the building will be used as a fulcrum on which the building will turn like a see-saw. The weight on one side of the fulcrum will help to balance the weight on the other side. It is only the difference in



DIGGING AWAY THE EARTH FROM UNDER THE UPTILTED EDGE OF THE BINS.

OPERATING THE JACKS AT THE "K" PIERS.

weight between the two sides that will have to be lifted. By means of powerful lifting-jacks the men can swing the building on its fulcrum, then after it is straightened up considerably they will shift the fulcrum forward to the next row of piers, which will raise the building to a still higher level, or within about fourteen feet of its original level."

Much to the regret of the boys, Mr. Barto could not wait longer to see the work of jacking up the building. They did not realize that months would elapse ere the bin-house would be back on an even keel. The jacking operation was very slow. The jacks were operated by big steel bars six feet long, with three men to the bar. The bin-house was moved only a few inches per day, and then much time was taken in building up the piers and blocking them up under the concrete mat. It was not until the fall that the work was finished. Perry had almost forgotten the tilted elevator when, one day, he received a long letter from Mr. Abbe, telling him all about the work, and how it had been finished almost exactly on scheduled time.

CHAPTER IX

KELLY'S GASOLENE ELEPHANT

"LOOK, Jack, look!" cried Perry, clutching his chum's arm and pointing down the road. "What do you call that?"

The boys were out sight-seeing in the suburbs of Chicago while Mr. Barto was attending a conference in the city.

It was indeed a most extraordinary sight that Perry pointed out. There in the middle of the street, too far away to be distinguished very clearly, was an object that looked like a small house, but it was going through the strangest, spasmodic motions.

"What in the world is it?" exclaimed Jack.

"It must be a house they 're moving; but for the life of me I can't make out why it bobs up and down so."

"It looks to me as if it were walking," said Jack. "See those feet at each side. There—it is lifting them! Now it is planting them down on the ground and raising itself on them."

"You 're right, Jack," agreed Perry. "It *is* a walking house!"

Both boys started on a run to get a closer view of the curious object. As they drew nearer they saw that a long steel boom projected from the rear of the contraption, and a drag-bucket was suspended from the boom. There was a big gasolene-engine aboard the strange craft, and a lot of gear. It was very evidently an excavator of some kind, but never had the boys seen such a curious means of locomotion as this machine possessed.

They stared at it for a moment, and then both burst out into shouts of laughter. It was a most ridiculous spectacle. Here was this big, awkward machine sitting on a broad turn-table, while at either side were the feet, each consisting of a pair of I-beams with wooden treads. Each foot was attached by a chain to a cam. The cams were mounted on a shaft driven by the engine of the excavator. As the cams went around they lifted the feet off the ground and carried them forward. When the feet were firmly planted, the cams rolled along upon them, lifting the machine—turn-table and all—off the ground and moving it forward. Then the machine sat down on its turn-table again while it dragged its feet forward. There were lugs on

the feet that fitted into notches in the cams, so that there was no chance for the cams to slip.

"It gets along more like a hop-toad than anything else, does n't it?" remarked Perry. "At every hop it has to sit down. It is certainly the funniest thing I ever saw. What in the world do you suppose they ever got up such a gear for, anyway?"

"Blest if I know," answered Jack. "The people hereabouts must be used to the machine. There 's no crowd out to watch it go by."

"Look, Jack! It 's going to turn a corner."

The machine was very deliberate. It traveled at the rate of about thirty feet per minute. It had come to a crossing, and now, with both feet lifted off the ground, it was slowly swiveling itself around on the turn-table.

"Well, is n't that neat?" exclaimed Jack. "It just sits down in its swivel-chair, swings itself around to a new point of the compass, and then gets up and walks off in a new direction."

"Please, Mister," said Perry, accosting a pedestrian, "what do you call that thing, anyway?"

"Oh, that 's Kelly's gasolene elephant," answered the man. "He rides home on it every Saturday afternoon."

"Why in the world does he do that?" asked Perry.

"Well, as long as the machine has legs, why not use them? That 's what *he* says."

"But I mean," stammered Perry, "what 's the machine for? It is n't intended to be a walking automobile, is it?"

"Well, hardly—when it takes an hour to come up from the meadows over there, and going cross-lots at that! No, I don't think any one would mistake it for a runabout," laughed the man.

"But what is it, anyway?"

"It 's an excavator, a 'drag-line' excavator, as they call it," explained the stranger. "They 're doing some drainage work with it down on the meadows."

"But," persisted Perry, "what 's the use of legs on an excavating machine?"

"Soft ground, my boy, soft ground," replied the man. "If you put it on wheels and tried to haul it over those meadows, the wheels would sink in to the hubs, and you could n't get anywhere. But this machine has big feet, and it can go over very soft ground without sinking in much, just as a man on snow-shoes can travel over snow that a man with plain shoes on would sink through. Soft ground makes hard travel-

ing for anything on wheels, because when the wheels sink into the ground, they make a hollow for themselves, and then to go on they have to roll uphill out of the hollow or else flatten down the mud before them. At any rate, they must push against a hill of mud all the time. But this machine walks just as well on soft ground as on hard ground, because of its broad feet, and because it picks itself straight up off the ground as it walks instead of sliding or rolling along. When it gets to the job, it lifts its feet off the ground, and the walking machinery is disconnected from the engine; then it can swivel around on its turn-table in any direction, like an ordinary excavator. When it has to move on to a new position, it merely lets down its feet and walks. Why, if it were not for this excavator, they would have to build a railroad out over the marshes to carry the machine, because the ditches are not deep enough for floating dredges. It is a wonderful invention, but we are so used to seeing it around here that nobody stops to look at it any more. Even the horses don't mind it. But I tell you what, when it first sauntered into this section, maybe there was n't a big commotion! The horses were scared to death; we had two bad runaways, although luckily no one was hurt."

"Well, I don't blame the horses," declared Jack. "I felt 'most like running away myself when I saw the beast limping up the road."

"Has n't it a funny gait, though?" remarked Perry.

"Yes; do you know, it reminds me of that fellow in Los Angeles I was telling you about; 'Flat-wheel Kelly' Jimmy Doyle said they called him, because he had such a queer way of walking."

"'Flat-wheel Kelly'?" echoed the stranger. "Why, that 's what they call the man that runs this excavator!"

"Must be the same man!" cried Jack. "I thought I saw a familiar face in the pilot-house of the craft, but I was so busy looking at the machine that I did n't pay any attention to the engineer."

"Why don't you get him to show us how the thing works?" suggested Perry.

"All right," and the boys ran up to the excavator just as it was turning into a yard.

"Is n't this Mr. Kelly?" cried Jack.

"That 's me name," came the brisk answer. "Ye 've got me number, all right. What 's the charge?"

"Well, my name is Jack."

"Jack? I would n't worry none about it if I

was you. It ain't such a bad name, ye know. I had a mule called Jack, once, and he was a credit to the name, believe me."

They all laughed. Evidently Kelly was in a humorous mood.

Jack made another start. "You know Jimmy Doyle, don't you?"

"Jimmy Doyle?" repeated Kelly. "Sure! What do you know about him?"

"Well, he introduced me to you in Los Angeles a year ago last winter, don't you remember? And you sent us up to Big Creek."

"Ye 're right, me boy. I remember ye now!" cried Kelly, grasping Jack's hand.

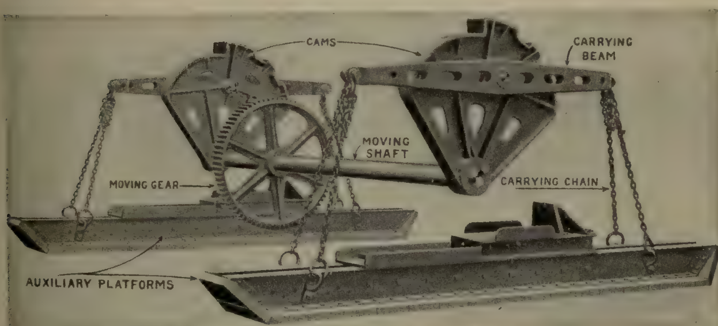
Jack winced. "This is my friend Perry," he said hastily, anxious to terminate that handshake. "Look out for him, Perry! He has a grip like a hydraulic press."

"Oh, I 'll not hurt ye," laughed Kelly. "I suppose ye come over to look at the machine. Come on in, and I 'll show the whole works."

He explained all the machinery, and even let the boys operate the walking mechanism. Needless to say they were highly pleased.

"Yes," he went on, "after I left ye at Los Angeles I come on east, thinkin' I might pick up a job more to me likin'. Ever since I got me leg hurt, I 've been lookin' for somethin' easier

THE "WALKING" EXCAVATOR.



THE "WALKING" MECHANISM OF THE GASOLENE ELEPHANT.

than sand-hoggin'. I 've tried me hand at most everythin', but I never thought I 'd be drivin' a steam hop-toad like this, and in Chicago of all places. I had n't been back here since I had the accident with me leg, and I never expected to come back here again with me 'flat-wheel.' "

"Oh, tell us about it!" exclaimed the two boys.

"It was a great piece o' work," began Kelly. "We was diggin' a hole in the lake—"

"A hole in the lake! What do you mean by that?" cried Perry.

"Why, a hole in the lake where the city gets its drinkin' water."

"You don't mean to say that Chicago gets its drinking-water from Lake Michigan, do you?"

"Sure!"

"But I should think it would be awfully dirty."

"Not where they get it from. They run a tunnel under the lake two or three miles out from shore. Then they come up through the bed of the lake to an intake that sets under water far enough so that it neither gets the dirt that floats along on top, nor the dirt that sinks down to the bottom. This tunnel I was workin' on was well over two miles long, and to save

time they started diggin' from both ends and the middle at the same time."

"But how could they dig from the lake end? How could they keep the water out of the work?" queried Jack.

"Why, that 's simple," interrupted Perry. "They sank a coffer-dam and dug down inside of that, did n't they?"

"Yes, almost the same thing—a crib we call it. We drove two rings o' sheet-pilin', one sixteen foot acrost and the other about eleven and a half. One ring was inside the other, and the space between was filled with clay—at least, that 's the way the half-way crib I was on was built. We had a great scheme for handling the rock we mined out o' the tunnel. We was about a mile from shore, so we rigged up a cableway—"

"What, a mile long!" exclaimed Jack.

"Yes, but it wa'n't all one span. Towers was set out in the lake about three hundred feet apart, and the buckets for the cableway could carry half a ton o' rock."

"But why did you send the rock ashore?" Perry inquired. "Why did n't you dump it into the lake?"

"Well, we did n't want to build an island out there," answered Kelly; "and then, too, they

needed that rock. They broke it up with a stone-crusher, and used it for concrete work in the tunnels.

"We had passenger-cars, too, on that cableway, but it was pretty slow traveling. It took seventeen minutes to make the trip to shore.

"Well, as I was sayin', there wa'n't no land out there, only just a crib and a two-story buildin' over it. Why, it was as lonesome as a lighthouse, only there was a hundred men of us there, night and day. You see, there wa'n't no way o' gettin' to shore except by the cableway, or by the tug that come out with the supplies to our crib and the next one."

"Did n't you have any boats?" asked Perry.

"Never a one; nor a raft, neither. Why, you could n't keep a boat out there. There wa'n't nothin' to protect us from the gales. The waves would 'a' smashed a boat to smithereens, and in winter the ice would 'a' crunched it to kindlin' wood. No, sir; they did n't think it would pay to have any boats; but say, there come a time when they wished they had them, all right! It would have paid, then.

"As I was sayin', there was a two-story house on the crib. On the top floor was our mess-room and bunks, and on the first floor was the

power-plant and the thawin'-room for thawin' out frozen dynamite.''

''Why! does dynamite freeze?'' exclaimed Jack.

''Sure it does! Ye know ye can't set it off when it 's frozen, so we have to warm it up in cold weather to get the frost out.''

''Is n't it rather risky?'' questioned Jack.

''Not if it 's done right. We was so used to havin' the stuff around that we must 'a' got rather careless. Why, I slept over that thawin'-room for months, with five hundred pound o' powder under me, and never lost a wink o' sleep over it.''

''What is a thawin'-room like?'' asked Perry.

''Oh, this wa'n't much more 'n a big closet with shelves to put the powder on, and on the floor was some coils o' steam-pipe, and there was a steam-gage set to keep the pipes from gettin' too hot.

''Well, I was in me bunk one mornin', just turnin' in from the night shift. A lot o' the men was in the mess-room eatin' their breakfast, and some was on their way down into the hole. How it happened, nobody knows. It might be the steam-pipes got too hot and some o' the powder dropped on 'em; but anyhow, that dynamite took fire.''

"You mean it exploded, don't you?" asked Jack.

"No, I mean it burned. Ye can burn powder without explodin' it as long as there is plenty of room for the gases to pass off. But say, it burns fast all right! In a minute the whole thing was ablaze. There was no use tryin' to fight it. A few o' the men did try to get a hose onto it, but the fire was too hot, and they had to run for their lives. They tell me there is only one thing a sailor is afraid of, and that is a fire at sea. Well, I believe it. There is nowhere to go except into the water, and when the water is ice-cold, it ain't the most comfortable place in the world to stay in.

"Be the time I knew there was a fire, the flames was shootin' up all around me. There wa'n't time for nothin' except to jump out o' bed and out o' the window, and the windows were choked with men tryin' to squeeze out. There wa'n't time to pick a good landin' place. I just jumped. Alongside the crib we had been dumpin' rock, which we had been takin' out o' the tunnel faster than we could haul it away with the cableway. This had piled up so that some o' the rock was stickin' out o' the water. As luck would have it, I landed on that pile o' rock. I 'm a pretty heavy man, but I was al-

ways light on me feet. I would have been all right, only I landed on a loose rock that give way under me and then rolled down and crushed me leg. There I was pinned be the rock, with the water up to me waist, and I could n't work meself free. It was cold water, too. There was big cakes o' ice floatin' around, and some o' the men swam to 'em and climbed on. I was most choked to death with the gases from the burnin' powder. The wind blew the smoke right over me, and the fire was so near I thought it would burn me head off while the water was makin' icicles o' me legs."

"Where was the tug all this time?" asked Perry.

"That 's what I was wonderin' meself. It seemed like I was lyin' there an hour, waitin' for that tug to come along, but I guess it was only about ten minutes, because the boat was just over to the other crib, and they come for us full speed as soon as they seen the smoke. I was just about all in when they grabbed me, and I did n't know nothin' till I woke up in the hospital."

That night the boys recounted their experiences to Mr. Barto and repeated Kelly's story of the crib fire. "I wish they were work-

ing on that tunnel now," remarked Perry. "Would n't it be a queer thing to do to take a two-mile stroll under a lake?"

"I 'll tell you what we can do," said Mr. Barto. "Chicago is n't the only city that gets her water-supply from a lake. It happens that they are digging such a tunnel at Cleveland, now. We 'll stop off there on our way to New York, and I 'll take you out for a stroll under Lake Erie, *four* miles from shore."

CHAPTER X

BORING A TUNNEL WITH A GIANT AUGER

THE water-supply tunnel at Cleveland was at a most interesting stage when our party stopped over to inspect it.

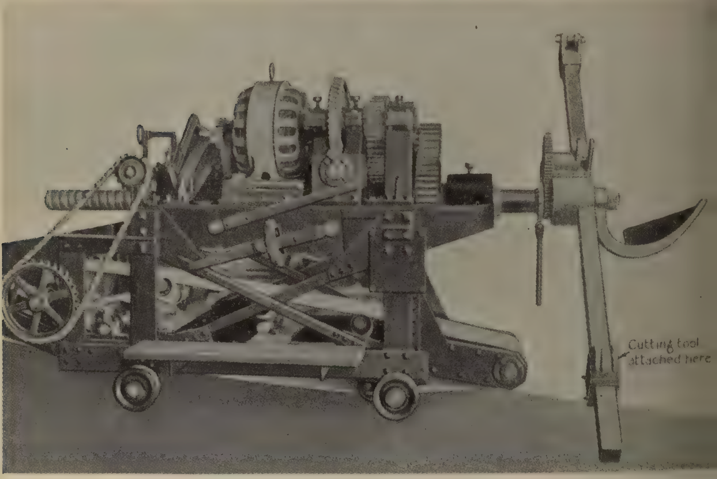
About a mile and a half from shore there was an old crib that covered the inlet of the first water-supply tunnel of the city. Later, another tunnel had been driven out to the same crib. The first tunnel was five feet in diameter and the second was seven. Now they were driving a new tunnel, ten feet in diameter, from this crib to a new one three miles farther out.

Mr. Barto and the boys were on their way to the old crib in a tugboat. As usual, Perry was full of questions. The first thing he wanted to know was how they got the water out of the old tunnels so as to get down into them and join them up with the new.

"Why, they pumped them out," answered Mr. Barto.

"But," persisted Perry, "they must have closed off the inlets to keep the water from flow-

A SECTION OF TUNNEL CUT BY THE GIANT AUGER.



THE TUNNEL-CUTTING MACHINE.

ing in; then what I want to know is how the air could get into the tunnel to take the place of the water."

"But they did n't close the inlets," said Mr. Barto. "They left them wide open."

Perry looked puzzled.

"All they had to do," continued Mr. Barto, "was to raise the inlet pipes above the water-level, which meant merely adding a few feet more to the shafts. It was a simple matter to pump out the seven-foot tunnel, and there is a railroad in it now to carry materials out to the crib. But the second, or five-foot, tunnel gave lots of trouble. The pumps could n't seem to get ahead of the water it contained. It was very evident that there was a leak somewhere. But where was it? That was the problem. It was impossible to go inside and look for the leak, and it seemed a hopeless task to hunt for a break that might be anywhere along the whole line of a tunnel a mile and a half long. There was just a chance that the leak might be at the crib or near it, and so a diver was sent down. Sure enough, he found the trouble right at that very spot. It was soon patched up, and now the tunnel is cleared of water."

"But where does the city get its water from with these tunnels shut off?" queried Jack.

"These are not the only water-supply tunnels that run out under the lake," answered Mr. Barto.

At the crib a Mr. Palmer greeted the party and took it down into the tunnel.

"We are doing something rather unusual here," he said. "All other water-supply tunnels have been lined with brick, but this one is lined with concrete."

"Is there anything new about concrete for tunnel linings?" asked Perry.

"Well, yes, rather," replied Mr. Palmer. "In New York's under-water tunnels the lining consists of rings of cast-iron plates bolted together, and then the cast-iron is covered with concrete. Here we do away with the iron plates altogether, and just use big blocks of concrete curved like the cast-iron tunnel-plates. These blocks are reinforced and bolted together just like the iron ring plates."

"That must be more economical, but I should think the blocks would be pretty heavy to handle," remarked Perry.

"They are, but we have a machine to handle them. It is something like the machine they use in New York to handle the cast-iron ring plates."

Mr. Palmer led the way to the tunnel heading

and showed them the machine. It had an arm that picked up the blocks from the cars that brought them there. This arm could swing the block around to any angle and set it in place against the tunnel wall. Then bolts were passed through it that fastened it to the block previously laid.

"We have something else here that is rather novel," said Mr. Palmer. "I 'll warrant you never saw anything like this before. We are going through soft clay. It cuts like cheese, and there is no reason why we should n't bore through it as we would through a block of wood; so we have a giant auger that bores a hole twelve feet in diameter."

Mr. Palmer stopped the machine for a few minutes to explain the mechanism. It was a very simple apparatus. The central horizontal shaft of the machine carried a boring-knife shaped like a plowshare. This cut a conical hole in the end wall or heading of the tunnel, which served as a bearing for the outer end of the shaft. On an arm extending at right angles to the shaft there was a cutting tool. By means of suitable gearing this tool was fed outward along the arm, starting from the center, and, as the arm revolved while the tool moved outward, a spiral shaving of clay was cut from the face

of the tunnel heading. The shaving was about six inches wide and six inches deep. The clay was caught by a conveyer that carried it through the concrete-block-laying machine back to the laborers, where it was loaded upon cars and hauled out of the tunnel. Electric motors were used to operate the tunneling machine, as well as the block-laying machine. After the whole face of the heading had been shaved to a depth of six inches the machine was moved forward by means of jacks.

"What do you do when you strike a boulder?" asked Perry.

"We have to pick the rock out of the way," explained Mr. Palmer, "or we might even have to break it up with a bit of powder; but we don't expect to run across many boulders in this bed of clay."

"I wish there were some way of cutting through rock in the same way," remarked Mr. Barto. "We could make good use of it in New York."

THE GIANT AUGER BORING A HOLE TWELVE FEET IN DIAMETER.

CHAPTER XI

THE WORLD'S GREATEST BRIDGE

"WELL, boys, I think we shall have to make another excursion into Canada." Mr. Barto laid down the engineering magazine that he was reading and studied his companions with a whimsical smile.

It was clearly evident that Jack was far from delighted at the suggestion. He was impatient to get to the Big City and see some of the wonders that Perry had been telling him about. Perry did not seem anxious to prolong the tour, either, although he suspected that Mr. Barto might have something very interesting up his sleeve.

"My, but you greet my proposal with enthusiasm!" said the engineer, with a laugh.

"I hope," said Perry, "this is n't a job that will keep us waiting two months, like the grain elevator job."

"Oh, no," replied Mr. Barto. "This will be a pleasure trip; I want to take you to a great battle-field."

"A battle-field!" cried Perry. "What, in Canada?"

"Yes, an engineering battle-field. You know I have often likened the work of the engineer to that of a general. It is war, war, war, all the time, with ax and spade, with pick and shovel, with dynamite and powerful machinery; for we have to deal with the vast forces of nature,—torrent and tempest, avalanche and ice-pack, granite and quicksand,—there is no end to the forces at nature's disposal. As in real warfare, the attack must first be planned out on paper. Before the campaign is begun the lay of the land is plotted. Scouting parties are sent out to reconnoiter; the strength of the enemy and the dispositions of his forces are studied. Then the engineer summons his staff-officers, the plans are discussed, and each move is mapped out in detail before the actual contest begins.

"The place I want to visit is the scene of one of the mightiest battles ever fought by an engineer, and I am sorry to say that the result was defeat and absolute rout. It was the Bull Run of engineering. The trouble was that the army was under-officered; a weakness developed in the lines; the danger was not realized by the officers in immediate charge; and by the time

the commander-in-chief had been notified and had given orders to the others in authority to relieve the situation, the threatened spot yielded. The battle was lost, seventy-five men were killed, and over a million dollars' worth of material was reduced to a pile of junk.

"That battle-field is interesting just now, not because of a failure nine years ago, but because the fight has been taken up anew. The battle is now on, and it looks as if it surely must end in victory."

Mr. Barto sat back and watched the effect of his little speech. Both boys were at him at once with demands for a more explicit account of the battle.

"Jack," he said, by way of answer, "you remember Eagle Bluff, at Thunder River, don't you?"

Jack nodded. "Of course I do."

"I believe you and Perry did a bit of rough surveying to find out how far it was across the valley to Round Top. You made it about a third of a mile, did n't you?"

"Yes; seventeen hundred feet," answered Jack.

"Well, that is near enough," continued Mr. Barto. "Suppose you wanted to build a bridge across there how would you go about it?"

"What?" gasped Jack. "I don't believe it could be done! The gulch is too deep for any piers, and you could hardly do that in a single span."

"Oh, yes, you could," interrupted Perry; "you could build a suspension bridge across."

"Suppose," said Mr. Barto, "a suspension bridge would not do; suppose we needed something stiffer than that."

"Why," said Perry, "why, you would build a cantilever, would n't you?"

"But what is a cantilever?"

Perry looked blank.

"You know what a bracket is, don't you?" said Mr. Barto. "Well, a cantilever is merely a succession of brackets. Now I am going to describe the 'K' type of cantilever, because that has something to do with this battle we are talking about."

Mr. Barto took out his pencil and made a sketch similar to Figure 10. "Let us suppose," he said, "that this line *A* represents the rock face of Eagle Bluff; the first thing we do is to set a couple of bars, *B*, in niches in the face of the rock wall and swing their upper ends out, keeping them, however, from going too far

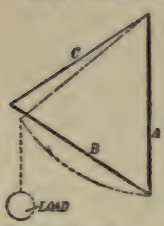


FIG. 10.

THE QUEBEC BRIDGE, REACHING OUT ACROSS THE ST. LAWRENCE RIVER—A THIRD OF A MILE FROM PIER TO PIER.

by means of the ties, *C;* you understand, of course that each line stands for two parallel members, one behind the other. The *B* members have to be fairly stiff; otherwise, if a heavy load is suspended from the brackets, they will buckle or bend as indicated by the dotted lines. So we will draw *B* with a heavy line to show that it is what a bridge engineer would call a 'compression member.' The members *C*, however, are never under compression and do not have to be rigid; so we will draw them with a light line to show that they are 'tension members.' Now, if we can put out one bracket from our wall, why can we not rig up a second bracket on the first?"

Mr. Barto amplified his sketch so that it looked like Figure 11.

"Let us hang a bracket A′ B′ C′ on the point of the first bracket *A B C*, tying back the upper end of the bracket by means of the member *D*. It will be evident that a load on this second bracket will exert a pull on the member *D*, and so this member may be put down with a light line to show that it is under tension. But if a heavy load were put on the second bracket it

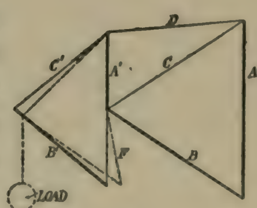


FIG. 11.

would break its back on the point of the first bracket (see dotted line, Figure 11); that is, the lower half *F* of the member *A* would be bent back unless we put in a brace, *E* (Figure 12), to

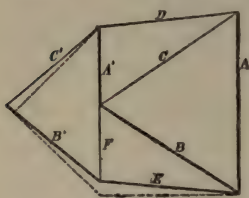


FIG. 12.

hold it in place. The part *F* may then be indicated by a light line, because there is no compressive strain on it. It serves to hold up the members *E* and *B* to keep them from dropping to the position shown by the dotted lines (Figure 12). This done, we can proceed to build a third bracket on the second one. You see that each bracket forms a sort of a 'K' (Figure 13) and this is what gives the name to this type of cantilever construction."

"But you can't go on putting on new brackets forever, can you?" asked Perry.

"Of course not. The longer the cantilever arm grows, the greater the pull on the upper part of the wall and the greater the thrust on the lower part of it. As long as this cantilever is being built out from the face of a rock wall

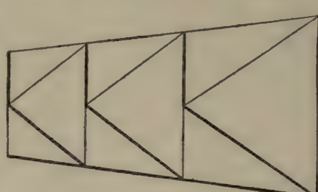
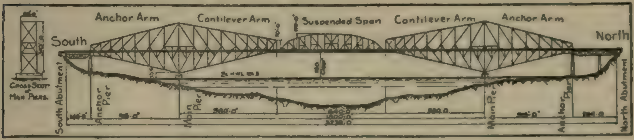


FIG. 13.

there is no danger of crushing in the abutment, but the top of the bridge would have to be anchored very firmly or it would tear loose under the powerful leverage of a long cantilever arm. Now, usually, a cantilever is built with two arms, running in opposite directions from a center post so that the pull of one arm will counterbalance the pull of the other.''

Mr. Barto spread out the magazine he had been reading. ''Here,'' he said, pointing to



Courtesy of "The Scientific American."
FIG. 14. "'TALL SHIPS MAY SAIL UNDER THOSE OUTSTRETCHED ARMS.'"

one of the illustrations, ''is the finest example of a cantilever bridge the world has ever seen, because it has a span of record length. The distance between those two piers is eighteen hundred feet. They stand fully a third of a mile apart, and yet their arms reach across that enormous expanse, without any intermediate support, and join hands at the center of the river, one hundred and fifty feet clear above high water. Tall ships may sail under those outstretched arms without having to lower their

topmasts. The anchor arms—that is, the arms that extend shoreward—are not so long as the cantilever arms, but the bridge has a length of three thousand two hundred and thirty-nine feet over all. Suppose we set this bridge in Broadway—you won't appreciate this, Jack—but suppose, Perry, we started it at Twenty-third Street. It would reach all the way to Thirty-fifth Street, and beyond. The floor of the bridge would run at the level of the top-story windows of the buildings along the way, while the towers themselves would be higher than the Flatiron Building."

"Where are the 'K's' you were telling us about?" asked Perry.

"Can't you see all the 'K's' facing the main posts? Those on the left-hand side are right side around, while the others are reversed."

"But what is the matter with the up-slanting arms of the 'K's'?" said Perry. "They seem to extend too far."

"Oh, I see what is bothering you!" Mr. Barto took the sketch of the cantilever he had been making and drew in the lines *G H* and *J*, so that the sketch had the appearance of Figure 15.

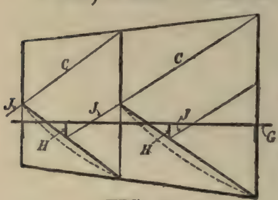


FIG. 15.

"Now *G* is the floor of the bridge," said Mr. Barto, "and it is supported on cross-girders attached to the lower halves of the *A* members. As the span between the brackets, or panels as they are called, is considerable, an extra support is provided by putting in the short posts, *H*. Then, to keep the diagonal compression members *B* from giving, under the extra weight, as indicated by the dotted lines, the tension members *C* are extended by adding the parts *J* to them."

"But what has all this to do with the great engineering defeat you were telling us about?" interrupted Perry.

"I was just coming to that," said Mr. Barto. "Eleven years ago they started building a similar bridge across the St. Lawrence River; it was an even more daring structure than this one. Work was first started on the southern half of the bridge; and when that was done, they planned to build out from the north shore so that the two cantilever arms would meet over the middle of the river. The southern cantilever had been built nearly to its full length when, one afternoon, one of the main compression members doubled up, and down went the whole structure into the river! That shows how all things are related to each other in a cantilever

bridge. Everything is calculated to do its part, and if it fails, the whole structure fails."

"Had n't that member been calculated properly?" asked Jack.

Mr. Barto did not answer the question directly. "The compression members," he said, "have to be very much heavier than the tension members, even when the load they bear is the same, because they must be rigid. A compression member is very strong as long as it bears its load end on. You could stand on the point of a knitting needle without crushing it if you only had something to keep the needle from bending; but if the needle were deflected from a straight line ever so slightly, it would collapse at once. It is just so with a bridge chord. As long as the compression members remain rigid, they can carry their load easily. But once they start to bend they weaken rapidly. No bridge has ever been built with as great a span as that across the St. Lawrence, and, although the load that the various members would have to carry had been carefully estimated, not enough bracing was provided in the members themselves to keep the main compression chords rigid under the enormous strain they were to be subjected to. One of

the main girders started to bend. When it was noticed, it was only a couple of inches out of the straight line. Then it had to bear against a bending strain, as well as the end thrust of the bridge. It stood the strain for a couple of days, but the combination was too much for it. Suddenly it gave way and twisted up into the form of an S. Down tumbled the whole structure immediately."

"What happened to it all?" inquired Jack. "Did they fish out the steel girders and use them over again?"

"No, indeed," answered Mr. Barto. "Most of it is there at the bottom of the river. You know the St. Lawrence is very deep—two hundred feet at that point. It was hard enough to clear away the stuff on shore. It was such a tangled mass of enormous steel members that the only way to dispose of it was to cut it up into short lengths with the oxyacetylene torch. But all the material beyond low-tide level had to be left there on the battlefield.

"Well, boys, the question is still before you. Would you like to go to Quebec and witness the building of the greatest cantilever bridge in the world?"

There was no question in the minds of

the boys this time. Unanimously they voted "yea!"

When we hear of some great work of man or of nature, our fancy is apt to paint such a wonderful picture of it that the object itself proves disappointing. But there are a few things that surpass the wildest dreams of the imagination. The Quebec bridge belongs in this class. The magazine picture that Mr. Barto had shown the boys conveyed no idea of the stupendous dimensions of the bridge. It looked very slender and graceful as it was silhouetted against the sky. Now that they had a chance to see the bridge itself, they found that their conception of its size had been sadly deficient. For instance, the great bottom compression chords which Jack had supposed to be four or five feet deep at most, measured ten feet in depth, and men actually had to use ladders to climb up on them. The main piers of the bridge, which were so insignificant in the picture that they could hardly be discerned, stood 33½ feet above high water level, or, as Mr. Barto put it, "as high as an ordinary two-story-and-attic cottage." The piers were of granite blocks, and in each pier a hundred and seventy-six holes had to be drilled for the anchor-bolts of the main shoes of the cantilever.

ONE OF THE MAIN SHOES, SHOWING THE HEAVY COMPRESSION MEMBERS SECURED TO IT.

Of course, all that work had been completed long before, but the visitors were told that if all the holes in one of the piers were added together their diameters would reach a sixth of a mile.

It was a noisy place. There was the rumble of cars bringing up new masses of metal, the clanging of steel against steel as giant pins were hammered into place, and the incessant racket of the riveters.

A Mr. Genung was explaining the work to Mr. Barto. Perry caught but a snatch of the conversation.

"The first thing we did was to build the floor," Mr. Genung was saying.

"How is that, sir?" Perry interrupted. "Have n't you got that twisted?"

"No, not at all. The floor was built first from the anchor pier to the main pier. After that we built the rest of the anchor arm about the floor."

"But I don't understand," said Perry. "I thought the whole idea of this network of steel was to carry the floor. If you could put up the floor without it, what was the use of putting in the rest of the steel work *after* you had finished the floor?"

Mr. Genung and Mr. Barto both laughed.

"I knew you were joking!" cried Perry.

"No, I 'm not," protested Mr. Genung. "We really did build the floor first. The floor was supported on temporary staging resting on the ground. When the floor was finished as far as the main pier, that big traveling erector was set up; with it the anchor shoes were set in place on the main pier, and then we worked back towards shore, building the bottom chords. These had to be supported on temporary staging, too. This done, we worked from shore toward the main pier, putting in the rest of the members."

The "traveler" Mr. Genung was speaking about was in itself an impressive piece of work—a skeleton tower of steel weighing a thousand tons. It was built to handle the enormously heavy bridge members, some of which weighed a hundred tons. It ran on its own tracks on the main floor of the bridge and it spanned the tracks, along the middle of the bridge floor, on which materials were brought forward, between the legs of the traveler, and picked up by the derricks or cranes.

"How tall is it?" asked Jack, gazing up at the towering structure.

"Two hundred feet," was the answer; "as high as a fifteen-story building. And up on

top of that tall tower are two traveling-cranes that can reach out about fifty feet beyond the face of the tower. It is no simple matter moving a fifteen-story building around."

"Does it really travel?" asked Perry.

"Surely, but not at very high speed, I must admit. We make about ten feet per minute when traveling on the 'high gear.' "

While the boys looked on, the cranes picked up two enormously heavy sections and hauled them up to position.

"I see now why they have two cranes on the traveler," said Perry.

"Why?" asked Jack.

"So as to balance the load, of course. It would be an awful lopsided strain on the tower to lift just one heavy piece at a time. Is n't that so, Mr. Genung?"

"There is no danger of upsetting the tower," answered Mr. Genung, "but it does relieve the strain to have the loads counterbalance each other. However, the main reason for doubling up is to save time; for time is money. This bridge is going to cost nine millions of dollars, and the interest on that amount of money amounts to nearly a dollar every minute. How would you like to go to the top of the traveler?"

"Fine!" chorused the two boys.

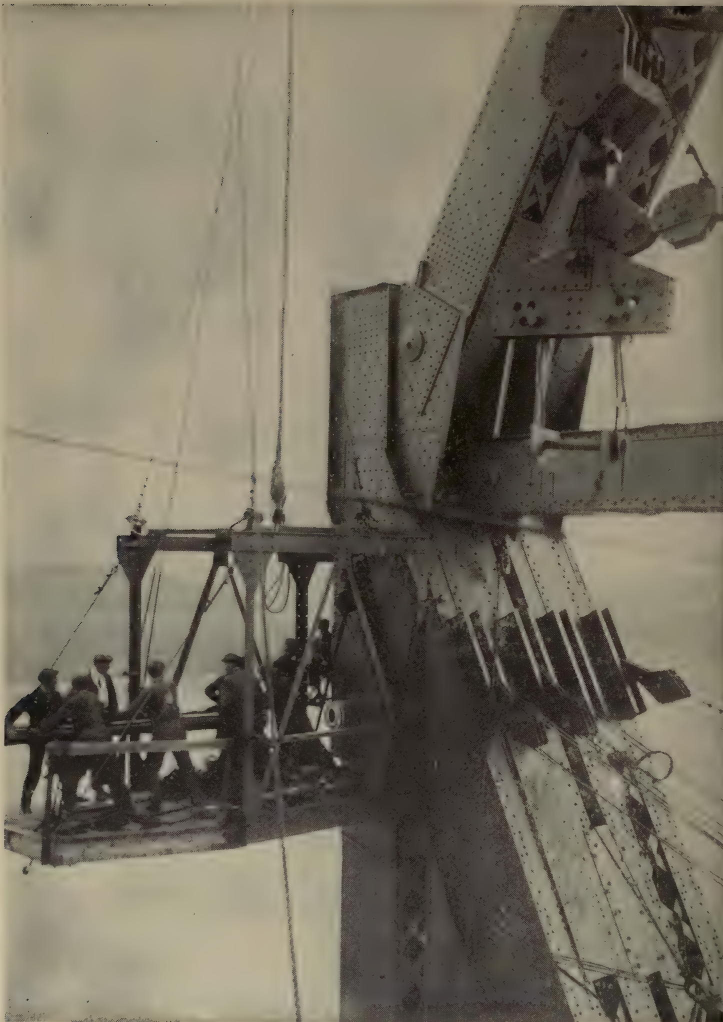
"You aren't afraid of getting dizzy, are you?"

"Oh, no," said Jack, "not we!"

"Here, Murphy," called Mr. Genung, "take these boys up and show them the view."

Mr. Barto and Mr. Genung stayed below on the operating platform of the traveler while the boys, in charge of Murphy, entered an elevator and shot skyward. A few moments later they stepped out upon a platform from which a flight of steps led up to the top of the tower. Just above their heads the two traveling-cranes rumbled by, swinging massive steel members from their long cables.

From their point of vantage the boys watched the workmen who were driving an enormous pin into a joint. The men stood on a platform that was suspended from the traveler. There were eight or ten of them, and they were using a piece of steel shafting about ten inches in diameter and eight or ten feet long as a battering-ram to drive the pin home. Of course, the shaft or battering-ram was too heavy for the men to lift, and so it was swung on a long cable from the top of the traveler. The boys had a bird's-eye view of the operation. They could see the cross-bars that had



THE WORKMEN WERE DRIVING AN ENORMOUS PIN INTO A JOINT.

been passed through holes in the shaft to serve as handles. The men seized these cross-bars and then with a "Heave, ho!" they swung the heavy battering-ram against the pin and drove it into the hole.

Looking across the river, Jack and Perry could see the other cantilever reaching out toward them.

"They must have worked faster over there than you," remarked Perry. "They have got way past the main posts."

"Yes," agreed their guide, "they had a much earlier start. They 've got as far as they can go. Now they have to wait for us."

"You don't mean to say they are half-way across the river?" exclaimed Perry.

"No, but they ain't goin' to build any farther. Ye know we ain't goin' to build all the way across the river from the shores. We had enough of that when the first bridge was built. We ain't goin' to take no such risks this time."

Perry looked bewildered. "What are you going to do, then?"

"We are buildin' the center span of the bridge on stagin' along the shore. When it is done, we are goin' to float half a dozen barges under it at low tide and then let the tide lift

the truss off the stagin' onto the barges. After that, we 'll float the span to the middle of the river and lift it up into place between the two cantilever arms; and believe me, that 's goin' to be one of the toughest jobs of the whole work! Ye see that span 'll have to be raised a hundred and fifty feet straight up in the air. They figure they can do it in about twenty-four hours. But with the heavy tides we have on this river it will be a ticklish job, all right!"

"I don't see," put in Jack, "why it is any safer to put up the span that way than to build it out all the way from shore; won't the cantilever arms have to carry the same load in each case?"

"Oh, no," said Murphy. "You fellers could pick up a pretty heavy log between you, but if that log was sawed in two, neither one of ye could hold up your half o' it; the sawed ends would be sure to drop to the ground. It 's the same with that center span; the cantilevers can pick it up and carry the weight between them, but if either one had to carry half of the span without the other end bein' held up, the leverage on that half would put a heavy strain on the cantilever. That center span is bein' built of nickel steel so that it will weigh as little as possible. Ye see, we don't want to run no chances like

on the first bridge when they tried to build all the way across from the two shores.

"Come on up here," exclaimed Murphy, leading the way to one of the cranes. "There is Big Bill. He was on the old bridge when she went down. Maybe he will tell you about it."

"Was he really?" cried the boys.

"Hello, Murphy," called Big Bill, as the party approached. "Is this visitors' day?"

"Right ye are! These two boys want you to tell them about the accident."

Bill sobered down immediately. "It ain't a subject I like to talk about very much," he said, "particularly when I am up here on the top of this traveler. Ye have heard about what caused it," he went on; "and to think there might have been no lives lost if only the girder could have held out a few minutes longer! One of the inspectors noticed the bend in the chord two days before it gave way, but they told us it was nothing. I tell you, though, everybody was nervous about it on the bridge that day. They knew this beam was doing its best to bear up under the load. I was running a locomotive on the bridge at the time, and I said before starting out on that last run that any trip might see my finish. It was late in the afternoon. In another fifteen minutes the whistle would

have blowed to quit work. All of a sudden there was a wrenching, grinding noise, and the bridge gave a lurch forward. I knew something was the matter and put on the brakes at once. I can see the bridge going down now. It went deliberate-like, and even though the brakes was on, my engine coasted down the bridge and fell off the end. You can see for yourselves that it 's a big drop from the bridge floor to the water. I don't know what happened. Somehow or other I got free from the engine, and they picked me up more dead than alive. My partner, Dave Carter, was saved too. He was on the bridge, but near the end of the anchor arm. When he felt the bridge going he started running for his life. Fifty yards he ran, and uphill, because the bridge was dragging down. He just jumped for the anchor pier when the whole thing went down with a crash. It was a narrow escape, all right, and we don't either of us want another like it."

"I don't see how you have the nerve to work on this bridge after your experience on the other," said Perry.

"Lightning never strikes twice in the same place," was Big Bill's laconic reply.

THEY COULD SEE THE OTHER CANTILEVER REACHING OUT TOWARD THEM.

CHAPTER XII

BUILDING PIERS FOR 1000-FOOT SHIPS

JACK sat gazing out of the window. He was on the twenty-seventh floor of a downtown office-building in New York, and his eyes rested on a wonderful panorama; but his mind was elsewhere. Somehow, this lofty perch carried him back to Eagle Bluff, where Perry had suddenly entered into his life and destiny, over two years since. And a wonderful train of events had followed that meeting. Little had he guessed that that train would lead to the great city of New York.

Two weeks had elapsed since he had arrived in the big city, and a busy two weeks they had been. Mr. Barto had suddenly been stricken with typhoid fever on the very night of their arrival, and Perry had insisted on taking Jack into his own home, although the lad felt perfectly capable of taking care of himself. The first week was spent in seeing the wonders of the city, but finally Jack had protested.

"Really, Perry," he said, "you 're giving me an awfully good time, but I must get to work. Why, I have been loafing ever since I left Copper Center."

"What 's your hurry, Jack?" exclaimed Perry. "You need n't worry about your room and board while I have a home."

"That 's just it," Jack had replied. "I can't go on living on my friends. I am sure I did n't earn my salt at Copper Center; Mr. Barto just made a job for me. And here I am in New York, living in your house and eating at your table, when I ought to be out earning my own meals." Perry's laugh had nettled him. "My, but are n't we getting independent," he had said.

"What are *you* going to do?" retorted Jack. "Live on your father all the rest of your days?"

"Oh, no. When a good job comes along, I 'll take it."

"I 'm not going to wait for a job," Jack declared. "I 'm going to hunt for a job. I 'm going to be an engineer, and so I have got to get into some engineering office. I don't care what I earn, so long as it is enough to keep me going while I learn something at a night school."

Perry had chimed right in with him. "Say,

Jack, we are going to school together, and you can board at our house."

"Fine," Jack had answered, "all but boarding at your house. I can't afford to pay what your meals are worth, and I 'm going where I can pay for what I get."

"Then I 'm blest if I don't board with you, if Dad will let me; at least, while the folks are away for the summer."

So here they were in an engineer's office. It was the influence of Perry's father that had obtained work for them in the same place, although the boys did not know that. It was Saturday noon; their first week's work had ended. There was a lull as the men waited for their pay envelopes; and while he waited Jack was turning these things over in his mind as he stared vacantly at the busy harbor spread out beneath him.

He was brought back to present realities by a hand on his shoulder and Perry's voice saying: "Hello, Jack, what are you looking at? Oh, I see—that ocean liner. She 's pretty big; but I have seen much bigger. You know that the latest of them run as long as nine hundred feet and over. If you set them on end, they would tower above the tallest building in New York."

Jack's eyes opened wide. "You mean, they are two or three times as big as that fellow out there?"

"Say, how big do you suppose that one is?"

"It must be three or four hundred feet, anyway," reckoned Jack.

"You 're away off," announced Perry. "She 's a good six hundred feet long, I should say. Why you could cut her in two, and still she would reach from the ground to this window."

"How do you know?" demanded Jack.

"I know all these big boats by sight," declared Perry. "I have seen them come and go for the last seven years."

"Yes," chimed in another voice, "she 's a big one, all right and it won't be long before we have thousand-foot boats." It was a young man named Harris who spoke, craning his neck to see over their heads. "They are getting so big," he went on, "that it is a problem what to do with them. You know the city is building thousand-foot piers up at Forty-seventh Street, and our company has a contract for them."

"That 's rather queer, is n't it?" said Perry. "I thought we went in for foundations mostly."

"We do," answered Harris, "but this is really a foundation job."

Courtesy of The Scientific American.

THE PIERS FOR THOUSAND-FOOT SHIPS, AS THEY WILL LOOK WHEN COMPLETED.

"Yes; I suppose driving piles is foundation work, of a kind, but that is not my idea of foundation work," Perry answered.

"You take a run up there, young fellow," Harris returned, "and you 'll soon see it is n't a job to be sneezed at. It is the biggest piece of work of its sort ever attempted."

"What is so wonderful about it?" queried Jack.

"Listen. You can't go on building piers farther and farther out into the river, or you will soon choke it. A thousand feet is nearly a fifth of a mile. The river is only about four thousand feet wide there, and if you took another thousand feet for a pier on the opposite bank, there would n't be much room for a thousand-foot ship to manœuver without crashing into one pier or the other. The War Department keeps an eye on waterways and won't let shipping encroach too much on the channel. At Forty-seventh Street the War Department has set a dead-line eight hundred feet from shore, and no piers must project beyond that line."

"But then how could they build piers one thousand feet long?" interrupted Perry.

"Wait a minute, can't you?" cried Harris, impatiently. "I was just getting to that. As long as they could not extend the piers a thou-

sand feet into the river, they had to run them back into the land, see?"

"Into the land?"

"Yes; they tore down a lot of buildings on the river front, storage buildings, stables, gas-tanks, old shacks, and so forth, and what we are doing now is to move the shore line inland a couple of hundred feet. That 's where the hard work comes in."

"Why, it ought to be a simple matter to build the piers right on the land and then dredge out the earth between them, I should think," said Jack.

"It sounds very simple," said Harris, "but you see these big liners draw a lot of water, and we have to have a depth of at least forty feet there at low water. Now it happens that we strike rock long before we get to that depth; and, unfortunately, there is no simple way of digging out solid rock without getting right down to it and blowing it up with dynamite. So we are building a great coffer-dam, the biggest one in the world, to keep the river out until we have prepared this new bed for it. I suppose you know what a coffer-dam is?"

"Oh, yes," said Percy; "we were on the Thunder River job and built a good-sized coffer-dam there."

"Yes," said Harris, "I have read all about that job, and it was a difficult piece of work, too, but it was a mere peanut-shell to this one. Why, boy, this coffer-dam is the biggest and deepest the world has ever seen. It uncovers a space three hundred feet wide by eight hundred feet long and at least forty feet deep below the water at low tide; and say, at the toe of the dam we have to go down sixty-eight feet below a high-tide level before we get to rock. You can imagine there is some pressure against that wall with no way of bracing it against the opposite side, as you did in your little coffer-dam."

"I suppose the pressure must be tremendous, with the whole Atlantic ocean pushing against it," remarked Perry.

"Thunder and lightning, boys! Do you mean to tell me that you have n't learned that yet?"

"What?" stammered Perry.

"Why, that the volume of water has nothing to do with the pressure."

"Why, I supposed it was the weight of the water that made the pressure, and the whole Atlantic Ocean must weigh more than Thunder River."

"Yes," replied Harris, "but it is spreading its weight over a much greater bed. All we

need to consider is the depth of the water. At a depth of sixty-eight feet the pressure at the bottom is nearly thirty pounds on every square inch. It does n't matter whether we have a stream five feet wide, or a sound five miles wide, or an ocean five thousand miles wide pressing against that wall, the pressure will always be the same for a given depth." They were interrupted by the arrival of the pay-envelopes, which immediately monopolized the attention of every one concerned.

As Jack and Perry were about to leave Harris spoke to them again. "How would you like to go up to the piers with me after lunch? That 's the way I spend my Saturday afternoons, looking around at different engineering jobs. I learn much more than I ever could from blue prints."

The boys were only too glad to accept this invitation.

When they arrived at the job, they found that the work looked surprisingly different from what they expected. What they saw was a big lake, with merely a wall separating it from the river.

"Why," exclaimed Jack, "I thought you said the bulkhead was being built along the shore, but it 's 'way out in the river!"

THE BULKHEAD WALL OF INTERLOCKING STEEL SHEET-PILING.

TESTING A GROUP OF PILES WITH 220 TONS OF CONCRETE BLOCKS.

"It was built along the old shore-line, but they have been dredging this out while they were building the dam."

"What did they do that for?" inquired Jack. "Wouldn't it have been much easier to haul out the dirt with steam-shovels, where they could see what they were doing?"

"Oh, no; dredging is much cheaper and easier. Those buckets scoop up enormous quantities of mud with very little effort; and it costs but a trifle to move a scow full of mud, while the same loaded on cars would fill a whole train."

The bulkhead wall was made of steel sheet-piling with interlocking edges, like the piling used at Thunder River. There were two rows of piling, tied together at regular intervals by cross-walls which divided the structure into a series of cells. Each cell bulged out almost in the shape of an ellipse. Stone had been piled at each side of the dam, and the cells themselves had also been filled with sand and clay so as to solidify the structure.

"It was some little job driving those steel piles," announced Harris; "they are seventy feet long, each in a single piece. Once in a while a pile would strike an old buried timber, and then it took a long time to drive it through

—sometimes an hour or more of pounding with a steam-hammer. That put the pile under a terrible strain, and it was quite likely to be bent out of shape. Several piles gave way because they had been so bent as to lose their grip on the piles at each side."

"But how can they tell whether they have struck rock or wood?"

"That 's simple. The pile rings when it strikes rock."

"What, through all that mud? I should think the mud would damp the sound."

"No, it does n't," declared Harris; "I have heard the ring myself. You can easily tell the difference between that and the dead sound it makes when the pile strikes wood."

The basin within the bulkhead had been more than half unwatered, but up at the northern end they were having a lot of trouble. Here a single row of piles led inland from the cellular coffer-dam. Under these piles the water was evidently running in a stream of dangerous proportions. The line of piles was being badly distorted.

"What 's the trouble?" asked Mr. Harris of one of the men.

"Why, you see it 's hard to get a tight seal between the ends of the steel piles and the rock.

Every once in awhile a pile will land on a point of rock, and that will leave a gap at each side of the point that the water can run through."

"Is n't there any way of stopping it?"

"Sure! We are calking the leaks now from the outside."

"From the outside? How do you get at them?"

"Do you see that wooden pile they 're driving? That 's how they are doing it. They are just making a hole in the ground with the pile. Pretty soon you 'll see them pull it up; not quickly, or the mud would flow right in and fill up the hole; but they 'll pull it up very slowly, so as to leave a good hole all the way down to the bottom. Then they 'll put a lot of sawdust and rubbish into the hole, and drive the stuff down with a follower, or blunt-ended pile. That will squeeze out the plug of sawdust and stuff into the mud, and make it close up the leak under the pile. It was much worse here a few days ago, but they have stopped most of the leaks now by calking them in this way."

"Say! There 's something interesting," said Harris, pointing out into the river. "Do you see those big blocks of concrete? That 's

where the end of one of the thousand-foot piers is going to be. You know, all that part inside the coffer-dam is going to be of solid concrete, while the rest of it will have to be supported on wooden piles. It 's about a hundred and fifty feet down to rock out there, and they can't expect to use piles as long as that."

"Do they usually have to run down to rock with the piles?" asked Jack.

"Well, they would like to when they go through such soft mud as this. Why, they can drive ninety-foot piles clean out of sight with a few blows of the pile-driver. They are trying a scheme of lagging the piles, and then capping a bunch of them and noting how they withstand the pressure."

"What do you mean by lagging?" Jack inquired.

"Why, they bolt four pieces of five-by-six-inch squared timber on each pile," explained Harris. "That gives a much bigger hold of the piles on the mud. Sixteen of those piles are fastened together at the top, and a platform is laid on them. Then those great blocks of concrete, weighing altogether two hundred and twenty tons, are laid on the platform. In one of the test groups the piles are farther

apart than in the other, and they seem to be doing better work."

"Why?" asked Perry. "Is it just because they are farther apart?"

"Yes, the piles have a grip on the mud that tends to pull the mud down. This strain on the mud must be greater near the pile than it is farther away. If the piles are too close together, the mud strained by one pile would also feel the strain of the next one, and would not be so able to bear up as if the piles were farther apart.

"But, say talk about mud! I will show you a job next week that will open your eyes. That is one of our jobs, too."

At the shore side of the excavation they had already started blasting away the rock. Instead of using pneumatic bench-drills, they were boring deep holes with a well-drill. A heavy steel shaft, with a chisel-like cutter on the end of it, was dangled on a rope, so that when the machine was at work, it hammered the rock and chipped out a hole in it; the hole was six inches in diameter and about forty feet deep. Into this was put a charge of about one hundred pounds of dynamite, enough to fill the lower four feet of the hole, which was then filled with sand. After that, another charge was put in and tamped with sand; and finally a third

charge. When the blast was fired, the rock heaved up, and was shattered without flying into a thousand fragments, because the blast was buried so deep.

"After they get this all excavated, what then?" asked Perry.

"That 's the worst of it," said Harris. "Most engineering work is built to stand, and the engineers can point with pride to it for years and years; but this coffer-dam, although it is the biggest the world has ever seen, and although it took months and months to build it, will all have to be torn down again and every trace of it removed."

"Will they blow it up with dynamite?" asked Jack.

"Not by any means," declared Harris. "Why, there are hundreds of tons of valuable steel there. No, every piece of that sheet piling will have to be pulled up again!"

CHAPTER XIII

DAMMING A SEA OF MUD

THE following Saturday, Harris piloted Jack and Perry up to the wilds of the Bronx. It seemed an interminable ride, and it gave Jack some idea of the enormous extent of the great city.

They were nearing the end of the trolley line when Perry noticed a peculiar change in the landscape. In place of the green meadows on either side, there were vast patches of dirty gray, out of which projected the blanched trunks of dead trees. It was as if a volcano had showered its hot ashes over them, quenching their lives, scaling off their coats of bark, and covering the earth about with a dull drab shroud.

"What do you call that?" cried Perry.

"It is some of the mud we excavated from the river," explained Harris. "We filled in some of those low meadows around here."

"But what has happened to the trees?"

"The mud killed them."

"Mud? Why should it?"

"Because it 's salt mud. The East River is salt (it is an arm of the sea, you know), and of course the mud is salt, too. In time, I suppose the rains will wash out the salt and the mud will be covered with grass, but those trees are done for, all right."

The trolley-car came to an abrupt stop.

"Here we are at the end of the line!" cried Harris. "Now, if we are lucky enough to find Mr. Slocum, I guess he will let us take the boat over to the bulkhead."

At the office they learned that Mr. Slocum had just started for the bulkhead himself. "If you hurry to the pier, quick, you may catch him before the boat puts off," they were told.

A bank concealed the pier from view. Up over this the boys ran. They could see a couple of men sauntering down to a motor-boat that tossed impatiently on the swell of a passing steamer.

In response to Harris's hello the men halted, and in another moment the three breathless runners had joined them.

"Say, Mr. Slocum, would you mind taking us over to the bulkhead?" asked Harris. "These are two new boys that the company has just taken on, Jack Winans and Perry Carpenter,

THE MUD WOULD SLOWLY RISE LIKE A WAVE CREST.

THE TANGLE OF PILES.

and I am showing them what the company is doing."

"Good idea," agreed Mr. Slocum. "The best way to learn engineering, or 'most anything else for that matter, is to get right out and see the work with your own eyes. Jump in, boys."

It was a short run to the bulkhead—about a thousand feet.

"Well, boys," said Mr. Slocum, "I suppose Harris has told you about the queer job we have here?"

"I have n't told them anything much yet," replied Harris. "You know I have n't been here in a long time, and I don't know just what you are doing."

"You did n't tell them we were building a dam?"

"A dam!" exclaimed Jack. "Where?"

"Why, under that bulkhead."

Perry and Jack were puzzled.

"It is one of the queerest jobs I ever had anything to do with," went on Mr. Slocum. "You know, what we are trying to do is to build a quay with at least thirty feet of water alongside it, at low tide, so that big ships can tie up to it. But the water is very shallow here. There is a great mud-bank that slopes out very gently

to the channel. The mud is anywhere from twenty to forty-five feet deep, and in some places it is sixty-five feet down to hard bottom. Well, the idea is to dredge out all the mud between the channel and the bulkhead and fill it in behind the bulkhead, in that way building new ground for the warehouses and factories and such buildings that are going to stand here where you see nothing but water now. That sounds simple, does n't it?"

"Yes," nodded Perry.

"But that mud," went on Mr. Slocum; "why, it is so soft that we could n't use a bucket-dredge on it; we had to draw it up with a suction-dredge. The only way to keep the bottom clear of mud on one side of the quay, and to keep the ground from sinking on the other side, is to build a dam to hold back the mud-fill."

"That is what this bulkhead is for, then. is n't it?" asked Jack.

"Oh, no, this is just a wall of piles; the mud would flow through it freely."

"But could n't you drive a wall of sheet-piling along the bulkhead?" asked Perry.

"My dear boy, you have n't any idea what a pressure there would be on that wall. This bulkhead is just built to carry the quay wall.

To keep the mud back, we are building a dam of rock.''

The boat had reached the bulkhead by this time.

''What an awful tangle of piles, Mr. Slocum,'' said Harris. ''They look as if they had been put in helter-skelter, without any rime or reason.''

''They do look like a mad jumble,'' admitted Mr. Slocum, ''but, you know, every one of them has been placed with the greatest care and precision. Some of the piles are driven on a slant so as to take the thrust of the stone-fill that may bear against the bulkhead. Each pile is marked and numbered, so that the men can sort them out and bring them back into alignment when placing the capping-timbers on them.''

The party stepped out upon a lighter that was moored alongside the work. There was a hoisting-engine on board, with which heavy timbers were lifted and the piles were hauled into place. It was marvelous how order was brought out of that jungle of piles.

''Why do they get so badly out of line?'' asked Jack.

''That question has an interesting answer,'' replied Mr. Slocum. ''Before we drove this

line of piles we dredged out a channel down to hard bottom. Now, here is a funny thing: before we dredged, soundings showed us that hard bottom lay about forty feet below the low-water line. But when the mud had all been dredged out, we found that the bottom was only thirty-seven feet below the low-water level. How do you account for that?''

''Do you mean the bottom actually rose three feet?''

''That 's what I am asking you,'' replied Mr. Slocum.

''I suppose, when you took the load of mud off the bottom, it expanded or rose or something,'' suggested Perry.

''Do you know the answer?'' asked Mr. Slocum, turning to Harris.

Harris shook his head. ''Sounds queer to me,'' he said.

Mr. Slocum's eyes twinkled as he watched the puzzled expression of the boys. ''I 'll tell you something else,'' he said. ''Before we dredged, our explorations showed that the hard bottom under the mud-bank was gravel and coarse sand. When we dredged off the mud, we found that over the gravel bottom there was a three-foot layer of rocks and boulders. Now where do you suppose they came from?''

The boys were no nearer a solution of the problem than before.

"Why, the only way to account for it," explained Mr. Slocum, "is that the rocks and stones were floating in the mud. The suction-dredge could not drag them out with the mud,

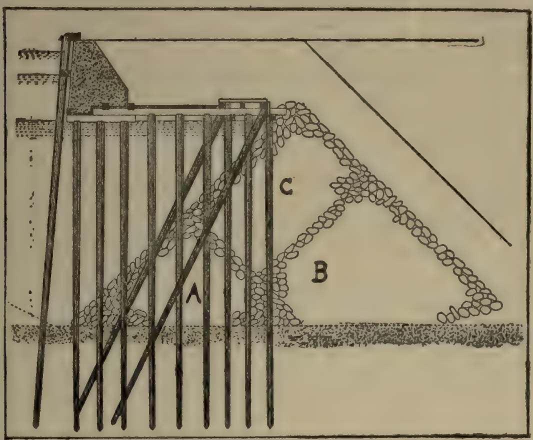


FIG. 16. CROSS-SECTION OF BULKHEAD.
A, first fill from cars on bulkhead; B, fill from bottom-dump scows; C, fill from cars on bulkhead.

and they were left as a sediment at the bottom. It is that layer of rocks that pushes our piles around helter-skelter; but you see it is a simple matter to pull them back into place again."

At the far end of the bulkhead, the part that was already finished, there was a light trestle

that ran to the shore. It carried trains loaded with rock.

"We are dumping the first fill of rock," said Mr. Slocum, "around the piles that have been capped. The second fill will be dumped from scows back of the first fill, and we shall let the rock sink through the mud to the bottom. Then we 'll dump the third fill between the other two. [See the drawing.] To close up all the holes between the rocks, and to make the dam tight, we 'll then pump dry earth over the inshore side of the rock dam. After that, we can go ahead with our dredging, filling in behind the dam. A flooring of timber will be laid on the capping of the piles, and on this will be built our concrete quay-wall up to a couple feet above extreme high water. All the space back of that will be filled in with made ground about twelve feet deep over the flooring of the bulkhead."

"Do you mean to say," asked Perry, "that all that wall and earth will rest on a timber deck?"

"Yes. Oh, it will be strong enough."

"But won't it rot out in time?"

"No; timbers that are constantly wet don't rot. At very low tide the deck may be uncovered for a short time. But it won't have

time to dry, and timbers don't decay except where they have a chance to dry between wettings."

"I can't get it through my head," put in Jack, "why you had to dredge a channel before driving the piles for your bulkhead."

"Ever hear of mud-waves?" asked Mr. Slocum. "No? Well, probably you didn't notice the trestle over the mud-flats as you were coming out to the point. That trestle was wrecked half a dozen times. Sometimes it was just pushed out of place; then at other times, whole sections of it would be swallowed up by the mud. We drove piles for the trestle through the deep mud and into the hard ground below. Then we ran cars full of stone out on the trestle, and dumped the stone over the side. You see, we were trying to build a dam there without dredging out the mud first. Now, that stone would settle down into the mud very slowly and disappear. The mud would sink down with the stone until there was quite a depression where the rock had disappeared. That was the start of the mud-wave. At one side or the other of the depression the mud would slowly rise like a wave crest and finally curl over just like an ocean breaker, except that it took hours and days to do what the water does in

so many seconds. Those slow mud-waves were too powerful for our trestle to withstand, and it was wrecked time and time again. All we could do was to rebuild it and keep on dumping in rocks until they reached all the way to the surface. If you had seen those mud-waves, you would have realized why we preferred to build this bulkhead in a channel clear of mud."

The boys watched the workmen haul the piles into place, saw them off, and fasten the capping to them with enormous wooden pegs. It was wet work. The men had to stand in water up to their knees, at times, and saw off the piles below the water-line. It was only during the two or three hours of low tide that they were able to work at all.

A strong breeze was blowing from the south, and the tide was coming in fast. It was evident that the men would soon have to stop work. Every once in a while a wave, higher than its fellows, would sweep over the piles.

Mr. Slocum had just conducted his party back to the lighter when there was a shout from one of the men.

"Look!" cried Harris. "There 's a big fellow!"

The combined swell of a tug and a fast Sound steamer, augmented by the wind and inflowing

"DAN WAS SLIDING UP AND DOWN THAT SPOKE AS THE WHEEL WENT ROUND."

tide, was bearing down upon them. The boys on the barge watched the men on the piles brace themselves to meet the coming wave. The next instant Jack and Perry themselves were swept off their feet. Somehow the barge, instead of rising on the crest of the wave, was caught by the piles and held down, while the water poured over it and swept clear through from stem to stern. There was a hiss as it struck the fire-box under the boiler, and great billows of steam poured out of the cabin.

The boys picked themselves up laughing, and chaffed Harris for his serious and almost frightened expression.

"Nothing to laugh at!" cried Harris. "If that had been just a little higher, it would have reached the boiler, and then we 'd have had a fine explosion."

"You are joking," said Perry.

"Well, you ask Mr. Slocum if you don't believe me," Harris retorted.

That wave marked the end of the day's work. Every one piled into the cabin to dry his soaked clothing. Sam Jones, the big colored fireman, had to rebuild his fire which had all but been extinguished by the wave.

"Would the boiler really have exploded if the water had reached it?" asked Jack.

"Certainly not," replied Mr. Slocum. "Boilers never explode; but the water in it might."

"What do you mean by that?"

"The wave would probably have chilled the metal and shrunk it so suddenly that something would have had to give way; then there would have been a bang. You know that water will boil at two hundred and twelve degrees Fahrenheit, out in the open, but when it is confined in a boiler it may be heated way above that point without boiling, because the pressure keeps it in a liquid state. Then it is a really powerful explosive, ready to go off and smash things if it should get a chance. When the boiler bursts the pressure on the water is released suddenly and all the water flashes into steam, just as when dynamite explodes, it flashes into gas. There is an enormous amount of power in overheated water."

"Sam Jones kin tell ye somewhat about the power of a water explosion," said one of the men. "Ye know he was workin' over a boiler a couple of months ago when she went off; and Sam went off, too. He landed in a mud-bank, and we had a job diggin' him out. When we picked him up, he was holding on to his watch like it was a life-preserver or something."

"How long were you in the air, Sam?" inquired Mr. Slocum.

"T-t-to tell de truf, boss, ah doan know," stammered Sam. "Ah dun forgot to look at mah watch."

The remark was greeted with a roar of laughter. "That reminds me," said Mr. Slocum, "of a steam-engineer I once worked for—Dan Saunders. He had an old engine that really belonged in the junk pile. I expected any day that she would fly to pieces. Well, Dan was going over her one day trying to fix her up a bit; she had a big fly-wheel that ran in a pit in the floor. Now it happened that Dan dropped his monkey-wrench or something into the pit, and he stooped down to pick it up. Naturally he leaned against the fly-wheel. The throttle-valve of the engine had been leaking some; it did n't pass enough steam to start the engine going when she was standing still, but there was just enough steam leaking through to keep her going, once she was started. When Dan leaned against the fly-wheel he gave it just enough of a boost to start the engine; that threw him off his balance. In another minute it would have been all over with him, but quick as a wink he saw the only thing for him to do was to jump aboard that fly-wheel and grab hold of one of the

spokes. He did it all right; he made a flying leap, threw his arms and legs around the spoke, and hung on as tight as he could, yelling bloody murder all the time, while the engine slowly gathered speed. I heard him hollering, and came on the gallop to see what was up. There was Dan, just like a toy monkey, sliding up and down on that spoke as the wheel went round. First he would settle down toward the hub, and then he would go head first for the rim, with his coat tumbling over him, smothering his noise. His watch was flying out at the end of its chain and banging against the side of the pit. What a holler he did let out! By George, I did n't know he had such lungs. I did n't take time to deliberate. I knew there was something the matter with the throttle so I ran straight for the boiler and cut off steam there. In a couple of minutes I had him out, and my sakes! but was n't he mad! And, would you believe it? he was mad at me. 'You dunderhead!' he yelled, as he looked at his battered timepiece. 'Why did n't you grab me watch—did n't ye hear me holler?' "

CHAPTER XIV

NEW YORK'S CULEBRA CUT

IT was on their return from the visit to the work on the quay that Harris and the two boys ran across a most unusual spectacle. A large brick building was split in two from top to bottom and cables were wrapped around it near the top, as if to bind the two parts together. Men were at work on the cables, and a big crowd had collected to watch operations.

The boys elbowed their way in among the people.

"What 's going on?" asked Harris of one of the onlookers.

"Can't you see?" he said. "They 're tyin' up the buildin'."

"Tying it up?" exclaimed Jack, puzzled. "Why, what do you mean?"

"Mean what I say," was the curt answer. "The buildin' is split open and they are pullin' it together again."

"By jiminy!" cried Harris. "That 's what they 're doing, all right! See those turn-

buckles? I believe they 're actually trying to draw the two parts together and close the crack."

"But how did it happen to split open?" asked Perry of the man.

"The subway done it," was the terse reply.

"You should have seen her last week," volunteered another man. "They say that part of the building was built on good rock and the other half on soft, crumbly rock. They 're digging the subway through here, and first thing they knew that soft part caved in, and down came half the building."

"You mean it actually fell down?" asked Perry.

"Oh, no, it merely settled a few inches. They raised it with jacks. But you see there is still quite a gap between the two halves, and now they are pulling them together again. It 's a wonder there are n't more slides around here, with the rock so treacherous."

"This is nothing to what they have to do down at the Grand Central," interposed still another man. "There they have to connect up with the present subway, and because they don't want any grade crossings the new tracks will pass under the old ones and then come up between them and join them."

"Why, how can they come between them?" said Perry. "I don't understand you."

"Have n't you noticed that between Thirty-third Street and Forty-second Street the up-town tracks run in a separate tunnel from the downtown tracks? There is quite a space between the two tunnels, and it is there that the new tracks will come in, that is, the tracks for the express trains. The local tracks will come outside of the present line to connect with the present local tracks. They have to make the connection without stopping traffic, which makes it a very difficult piece of work, because during the rush hours trains run every ninety seconds, while even in the small hours of the night, there 's an interval of only seven minutes between trains. Then, to make it still worse, the rock is so poor they never know when there 's going to be a slide. They call that the 'honeycomb' because of the number of tunnels that run at different levels. You know, over the old subway there is a street car tunnel and under the old subway will run the new subway, and still farther underground, at Forty-second Street, there is another tunnel that runs to the East River and on under it to Long Island City."

"Say, we must take a look at that next Satur-

day,'' said Harris. ''I think I know where I can get a permit.''

''It will open your eyes,'' declared the stranger. ''I 've been visiting different parts of the subway every Saturday for the past two months, and I have n't begun to see all of it. I tell you, this is a bigger engineering job than the Panama Canal.''

''The Panama Canal!'' quoted Harris, incredulously.

''You don't believe me, do you? Well now, how much do you suppose the new rapid transit lines are going to cost?''

Harris shook his head.

''Three hundred and sixty-six million dollars,'' cried the stranger. ''That 's the estimated cost, and it 's pretty close to the cost of the Panama Canal, and—''

''Oh well,'' interrupted Harris, ''you can't compare them on cost alone. What 's digging trenches under the streets of New York, or boring holes under the river, to building the great Gatun Dam and cutting a mountain range in two and joining two oceans?''

''Wait a minute, now, that 's just the point. This work is not as spectacular as that down at Panama. I 'll grant you that. But they are digging fifty miles of subway here, and that 's

ten miles more than the length of Panama Canal. Of course the amount of earth and rock removed here is nothing like as much. But just look at the handicaps under which it is excavated. And remember, engineers don't measure the greatness of a piece of work in mere cubic yards, but in the difficulties that have to be overcome. Our engineers at Panama did not choose to have the surrounding hills slide into their ditch, but it did not matter so very much. At worst, it meant only a few million cubic yards more of excavation. I tell you, the subway contractor would be happy if he could plow his furrow through the heart of the city without a thought of the effect upon the surroundings. But, unfortunately, he must cut the side of his trench clean, for the Culebra Heights that tower menacingly on either flank, ready to slide in upon him, are costly buildings filled with precious lives, and the slightest disturbance of their foundations is sure to be attended with grave consequences."

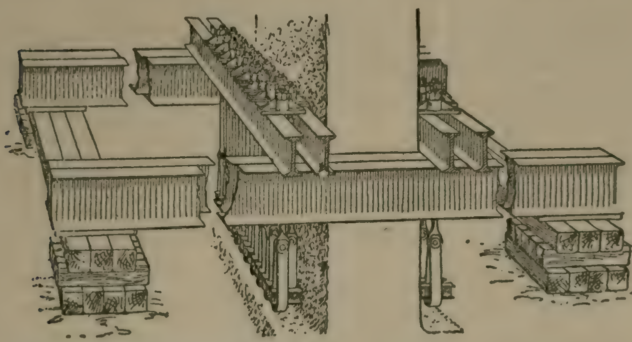
The stranger had evidently made quite a study of the subway and seemed to know what he was talking about.

"Take the William Street section of the subway, for example," he went on. "It is only a matter of a dozen blocks, and blocks are short

in that part of the city. Altogether, seventy buildings line the way and most of them are large and heavy. Twenty of them are from seven to twelve stories high and ten have from thirteen to twenty stories. Of all these, only three are built on concrete piers that reach down to rock. The contractor has estimated that it will cost him almost as much to keep the buildings from sliding in on him as it will to dig the subway past them.

"They have to work all sorts of ingenious schemes to support the buildings while the subway is being dug past them. Now there 's the telephone building in Brooklyn. It is eight stories high and very massive. The slightest displacement of it would mean more than a mere injury to the building. It would mean tying up the whole telephone system of Brooklyn, for part of the equipment of the Telephone Company is a series of very delicately balanced relays. Any disturbance of the level of the building would throw all those relay switches. Bed rock over there lies so deep that they can't extend the foundations down to it. The columns of the building each rest on a set of steel eyebeams imbedded in a mass of concrete. The ends of the eyebeams have been laid bare so that steel straps can be hooked under them. The

straps have been hung from huge girders that extend to a good support at each end, and, by means of nut and screw, the weight of the columns has been taken off the ground. Work has been going on past this building all summer, and probably few, if any, of the telephone op-



Courtesy of "The Scientific American."

FIG. 17. METHOD OF SUSPENDING THE FOUNDATIONS OF A BUILDING.

erators know that the building is actually hanging by its boot straps."

A knot of people had gathered around the speaker, but he was so interested in his subject that he did not appear to notice them.

"There 's another very ticklish place, too," he went on. "It is where the Seventh Avenue extension of the subway runs diagonally over the tubes of the Hudson and Manhattan Rail-

way, at Christopher Street. There 's very little room between the tubes and the street surface. Yet the subway must not rest on the tubes, for they are not strong enough to support the weight, so a bridge must be built over them. But the ground in which the tubes are imbedded is very unstable, in fact, it is so jelly-like that they were afraid to uncover the tubes lest, when relieved of their burden, they would be pushed up out of the ground by the unbalanced pressure. It was even considered risky to drive piles for fear of disturbing the tunnels, and so they are going to support the bridge on a floating saddle of concrete which will spread the weight of the subway over as much ground as possible, and this saddle is being put down very gingerly, only a slice at a time, in narrow trenches.

"Then there 's another thing subway engineers have to look out for, and that is the sewer system. In order to be convenient to the public, the subway must run close under the streets, and so it cuts practically all cross-town sewers. These have to be diverted and run up or down town to a point where they can pass over or under the tunnel, and would you believe it, for every mile of subway built a mile of sewer will have to be reconstructed!

"Then, just under the street paving there are conduits for electric light, electric power, telephone, telegraph, fire alarm and burglar alarm lines, while gas, water, steam and pneumatic pipe lines lie bedded in a perfect maze. They all have to be taken care of."

The stranger paused and looked at the crowd of listeners in astonishment.

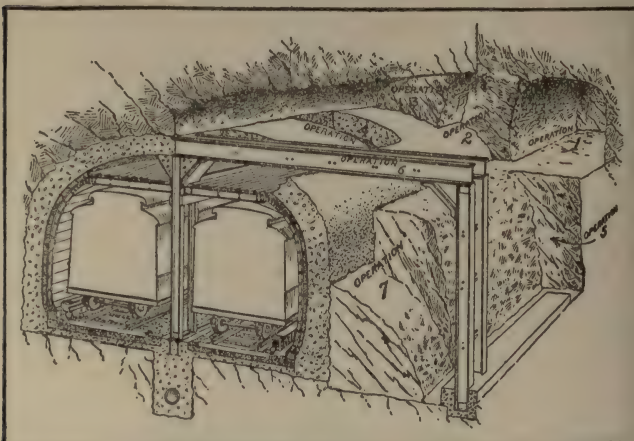
"Tell us some more," urged Perry.

"Don't know as there 's anything more to say," he answered. "I did n't realize I was giving a public lecture. But if you can get a permit to visit the subway work, you 'll have enough to see to keep you busy all summer."

Harris had a way of getting into any piece of engineering work that he wished to see, and he had little difficulty in obtaining the desired permit. The first place the boys visited was the "honeycomb." Looking out of the windows of the subway train on their way up to the Grand Central Station, they noticed that a wooden lining braced with steel ribs had been placed inside of the subway tube.

"Do you know," said Harris to his two companions, "I 've been looking at a blueprint of the work, and it is certainly a ticklish job. You know the core of rock between the uptown and downtown tracks is only just thick enough to

make room for the two new tracks when it is cut away, but it is going to be a mighty hard job blasting out that core without a slide of rock, because they will have to take away the center support of the two tunnels, leaving each tunnel arch with only one leg to stand on. To



Courtesy of "The Scientific American."

FIG. 18. METHOD OF UNCOVERING THE OLD SUBWAY UNDER PARK AVENUE.

make matters worse, the rock is full of seams that slant at an angle of about forty-five degrees. I believe they are going to have serious trouble peeling off the roof of the subway."

Harris questioned one of the engineers, a Mr. Lord, on this point before they went into the

tunnel. The engineer produced a sketch similar to Figure 18.

"There you are," he said. "There 's the whole story in one picture. This is a view looking south, and it shows you how the work on the northbound tunnel is proceeding. You see, we have to use a nibbling method. First a drift (Operation 1) is driven through the rock near the roof of the subway so as to leave a good mass of rock below to take the thrust of the arch. Then we cut toward the subway, uncovering the lining (Operations 2 and 3). After that a hole is cut in the subway roof (Operation 4). The wooden sheathing inside the subway will catch any material that falls from the roof. We dare not cut away the whole side of the arch at first, but can make only a small opening at a time. Operation 5 consists of cutting down from the drift to the full depth of the tunnel and putting in a pair of steel columns to support a pair of roof beams (Operation 6). The roof beams are wedged between the rock at the right-hand side and the standing arch of the tunnel. When this is done, it is safe to remove the rest of the tunnel lining at that point (Operation 7) and to put in steel columns between the tracks in place of timber support for the roof beams."

Mr. Lord accompanied the boys into the tunnel work and took the trouble to explain matters to them. Access to the work was had through a shaft which just missed the street car tunnel on one side and the subway tunnel on the other. The party went down in a large bucket.

The scene down below was most bewildering. A dense fog seemed to fill the tunnel. They could see only a few yards ahead. Here and there an electric light bulb threw a feeble glow and disclosed a mysterious gray figure, his face covered with a mask, bending over a machine that made a most deafening racket. The noise and poor seeing got on Perry's nerves, particularly when Mr. Lord snatched him suddenly out of the way of a carload of rock that was being pushed toward the shaft.

It was too noisy for talk down there. Mr. Lord shouted something that they could not understand, then he started up the tunnel, beckoning them to follow. They had to take to a trestle on which the cars ran and on which, between the tracks, was laid a single plank walk. The planks were wet and covered with a slimy ooze that made their footing very insecure, particularly in the dark stretches between the occasional electric lamps. Down below them they could make out, now and then, more of the

ghostly masked figures. On account of the thick atmosphere, it was impossible to tell how much of a fall they would have, should they slip off the trestle. At one point, where the light was very dim, the plank walk ended abruptly, and they had to step outside of the track to another line of planks. Perry shuddered at the thought of what might have happened had not Mr. Lord been with them to guide them carefully past this spot, for the ties of the trestle were widely spaced and it would have been easy enough to fall between them to the rock below.

Soon the seeing grew better, and the deafening racket began to diminish. They stepped off the trestle upon a floor of solid rock.

"Will you please tell me," inquired Perry, as soon as they had reached a point where they could talk without too much of a strain on the lungs, "what those ghostly figures were doing back there near the shaft and why they wore masks?"

"Look at your clothes," said Mr. Lord.

Perry found that he was covered with a gray powder. "What is it?" he inquired.

"Pulverized rock," answered Mr. Lord. "That 's the dust that the drills make. It 's bad for the lungs to have to breathe that stuff day

after day, so the men use masks, something like the gas masks that soldiers use in the trenches, except that these are not so elaborate because they are home-made.''

The tunnel narrowed as they proceeded.

''This is the drift that runs along close to the roof of the present subway,'' said Mr. Lord. ''You remember I showed it to you on the blue-print. It was marked 'Operation 1' and here is 'Operation 2.' '' He pointed to a hole cut in the side of the drift. ''You see we have uncovered a bit of the concrete roof of the subway. The rock is so poor here that we dare not uncover more than this much at a time.''

''Why, what 's the matter with the rock?'' asked Jack. ''It looks all right to me.''

For answer Mr. Lord picked up a fragment off the floor. ''Here,'' he said, ''is the rock we have to deal with.'' He broke it in two with his hands. ''We can dig it out with a pick, and after it has been exposed to the air for a time it gets so soft you can crumble it between your fingers. We would n't mind if it were all like that. Then we would know what we were dealing with. But much of this rock is very hard indeed, while scattered through it are seams and pockets of this soft rock. When we drill our blast holes, they may go through hard rock all

the way and yet run alongside a seam of soft rock. Then, if we load the holes with powder enough to shatter the hard rock, as we naturally would, an enormous amount of material will be blasted out and quite as likely as not we may have a serious slide. Usually the rock seams slant at a very awkward angle and although the slant is almost always in one direction, every once in a while we are surprised by a slide from the opposite side of the tunnel. Some contractors actually pin the layers of rock together to prevent slides."

"Pin them?" queried Jack. "How can they do that?"

"Why, they drill holes through two or more rock layers and drive heavy steel bars in the holes. Then they make a perfectly snug fit by forcing liquid cement in around them. But the scheme does n't always work very well. About all we can do in such ticklish jobs as this, is to be content with little nibbles and even at that, we never know when an avalanche of rock may come down upon us. With a street car tunnel above us and the subway tunnels below and beside us and with costly buildings lining each side of the street, we dare not take any chances."

CHAPTER XV

FIGHTING WATER WITH CEMENT

ONE morning late in the summer, the boys received a letter from Mr. Barto, asking them to come around to his office at 1:30 on the following Saturday afternoon.

It was the first word they had received from the engineer since he had been stricken with typhoid fever, and they had no idea that he was back at work. As his home was in a suburban town it had been impracticable for them to visit him during his illness, although they had called at his office on two or three occasions to inquire about him.

Mr. Barto was no less pleased to meet the boys again than they were to see him when they called at the appointed hour, although he did accuse them jocularly of deserting him, and going into the office of a rival company.

''I asked you over,'' he announced, after they had told him all about their experiences since arriving in New York. ''I asked you over with

the idea of doing a little sight-seeing this afternoon. How about it?"

"We are with you every time," replied Perry.

"Except the time I wanted you to go to see the Quebec bridge," he reminded them; "you balked at that, I believe."

"Well, we are not balking this time," said Jack. "What is it, another battlefield?"

"Yes," answered Mr. Barto, "and I am going to take you to a field of victory this time. But we have got to go a long distance, so we had better start at once, and I 'll tell you all about it on the way. I think you will agree with me that this is one of the pluckiest fights ever put up by an engineer."

Mr. Barto tucked an engineering journal under his arm and then they started forth. When they were seated in the elevated train he spread the magazine upon his lap and began the story.

"Bronx Borough, in the northern part of New York, has been growing by leaps and bounds. In 1890 it contained barely 89,000 inhabitants. Twenty years later the number had grown to over 430,000. When a district blossoms out like that it means a lot of activity in building new streets, new car lines, new sewers,

new electric light lines, gas mains, etc., to keep pace with the rapid growth and not retard it. Now this battle I am going to tell you about has to do with the troubles of the gas company in furnishing enough gas for the growing population. Not long ago it was realized that very soon the Bronx would be so big that it would outgrow the capacity of the gas plant located there. Just across the river from the lower end of the Bronx is Astoria, where there is a great gas plant; there you will find the world's biggest gas holder; it is 300 feet in diameter, and 242 feet tall; it holds fifteen million cubic feet of gas. They make both coal gas and water gas there."

"Water gas?" exclaimed Jack.

"Yes. I suppose you want me to explain that, don't you? When you blow steam over white hot coal you produce a gas that will burn with greater heat than common coal gas. The only trouble with it is that it makes a colorless flame and can't be used for lighting purposes except with a gas mantle; so they take this gas and pass it through crude oil; the gas then picks up from the oil the substance which gives a luminous body to the flame; such gas is called 'water gas.' It is rather a stupid name, on the whole, because it gives people the idea that the

gas is made directly out of water and so ought to be sold for considerably less than the gas company charges for it.

"But let 's get back to our story," said Mr. Barto. "It was thought best to run a tunnel across the river which would take a couple of big gas mains from the Astoria plant to the Bronx, and here," pointing to the magazine, "is the story of how it has been pushed through the rock under the river. The tunnel itself is 4662 feet long, but then if we count in the shafts at each end it is about a mile long; for the tubes run about 225 feet underground."

"Two hundred and twenty-five feet! Why, that is almost the height of a twenty-story building," put in Perry. "Why did they have to go so deep?"

"Because the river bottom is composed of rock and is so deep that they could not use the usual pneumatic shield method of tunneling," replied Mr. Barto. "They had to go through *solid* rock and by going as deep as that they hoped to get through without trouble. But it also meant that if they should have a serious leak they could not depend upon compressed air to keep the water out. A hundred feet or so below water level is close to the limit of depth at which men can work under pneumatic

pressure. Water one hundred and ten feet deep weighs 48 pounds on every square inch of the bottom. Not only is it a tax on a man to work under such pressure, but it is hard to get him out of the pressure without giving him the caisson disease. With two hundred and twenty-five feet of water over him it would be necessary to use twice as much air pressure as a man could stand to keep the water from pouring in.

"There was one spot along the line of the tunnel that was feared, and that was under the channel near the Bronx shore. A study of the geological formations and a careful survey with core borings showed that there was a lot of decayed or 'disintegrated' rock here and it was quite probable that they would encounter serious inrushes of water.

"Things went very smoothly at first until the trouble zone was reached. Then the utmost precautions were taken. Before each move ahead test holes were bored in all directions to try out the rock and see whether there were any dangerous faults in it. One day a test drill broke into a seam in the rock and water poured into the tunnel at a pressure of ninety pounds per square inch. A pipe with a valve on it, but with the valve left open, was driven

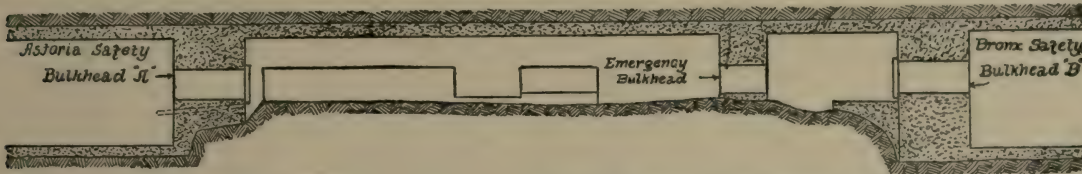


FIG. 19. SECTIONAL VIEW OF THE TUNNEL AT THE POINT WHERE THE TROUBLE WAS ENCOUNTERED.

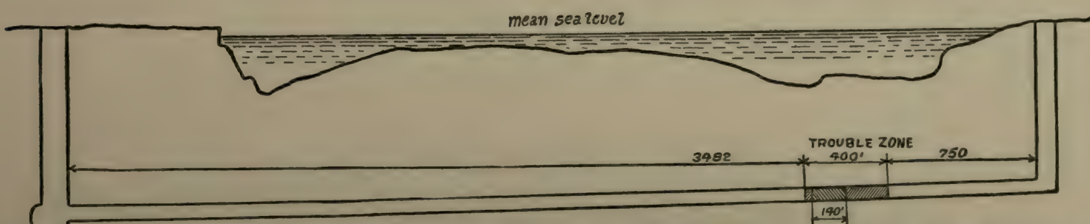


FIG. 20. PROFILE OF THE TUNNEL, SHOWING HOW IT SLANTS DOWNWARD TOWARD THE ASTORIA END.

into the hole. It had to be anchored very securely in place so that when the valve was closed the water pressure would not force the pipe out into the tunnel. Then grout, that is, a mixture of cement and water was forced through the pipe into the seam with the object of sealing up the leak, but it was difficult to accomplish anything. Apparently they could not get enough pressure behind the grout."

"How do they force the grout in?" asked Jack.

"It is very simple," explained Mr. Barto; "they use a machine that consists of a reservoir or cylinder with a trap door in the top of it through which they pour in the desired amount of cement and water; the mixture is usually about as thick as plain cream, although it may be as thin as skimmed milk. The cylinder has an outlet that is connected with the pipe that is to be grouted, and an inlet connected with a high pressure air main. First the valve at the outlet pipe is closed, then, as soon as the air inlet is opened the trap door is pulled up and is held tightly shut by the air pressure in the cylinder. Within the cylinder there is usually a set of paddles which are turned by an air motor and they stir up the cement and water thoroughly. This done, the

outlet valve is opened and the entire charge of grout is blown into the grout pipe by the air pressure.

"Well, as I was saying, they had all manner of trouble with that leak and then, one day, a large section of the tunnel wall caved in and a torrent of water poured in upon them. The pumps that were installed for just such an emergency were kept going at full speed, but they barely held their own against that inrush. With the water came in tons of green sand or decomposed rock, together with shells, refuse and mud from the river bed. Finally the seam in the rock must have been choked somewhat because the flow began to slacken.

"A bulkhead or wall was built across the tunnel and drain pipes were set in this wall to let the mud and water pass through while the wall was being built and the concrete was hardening. No attempt was made to stop this flow until the bulkhead was completed, and then the valves in the pipes were closed. This was the first line of defense. Back of it a second emergency bulkhead was built with doors in it that could be tripped or dropped instantly in case of necessity. Reinforcements were brought up in the shape of additional pumps. The space in front of the first bulkhead was

yielded temporarily to the enemy and then steps were taken to recover the lost ground. What do you suppose they did? I will give you three guesses."

Neither of the boys could offer a single suggestion.

"Why, since the rock was so poor," declared Mr. Barto, "they proceeded to make some good, sound artificial rock."

"Artificial rock?" gasped Perry.

"Yes, the general ordered up his artillery and through the pipes they had left in their first line of defense, they shot grout into the heading until the entire space in front of the bulkhead was filled with cement. When that had set they proceeded to cut through it, first with a drift or small tunnel. From this drift they bored into the faulty spots and shot in more grout. Gradually the drift was widened out. They had occasional serious reverses. At one time 2000 gallons of water per minute came pouring in upon them. Finally, after five months of persistent work, they succeeded in recovering all their lost ground and lining the tunnel with heavily reinforced concrete.

"Six months more of fighting netted them very little further gain. And so at last it was decided to discontinue the attack from the

"THE WATER CAME POURING THROUGH THE GROUT HOLES."

Bronx end and to concentrate all efforts from the Astoria side. Everything went well until they had penetrated to within 400 feet of the Bronx heading when, suddenly, their exploring drills struck a very heavy flow of water. The same tactics they had resorted to before were now used. They ran a small drift along one side and from this drilled into the seam and filled it full of grout.

"In that way they slowly pushed on, always scouting ahead with test holes and grouting whenever they encountered water. Of course, as fast as the tunnel was excavated it was lined with concrete. It is always hard to make a tight joint of the lining with the rock, and as is usual in tunnel work, holes were left in the concrete through which grout could be forced to fill up all cracks and crannies and make a tight bond between the lining and the rock. Once a very slight blast started an extra heavy flow of water. A bulkhead had to be built to cut off the flood and then the water backing up over the concrete lining, came pouring through the grout holes that had been left in it. At another time there was a tremendous flow and it seemed as if the whole river was pouring in. Hundreds of live fish came through."

"Fish," exclaimed Perry. "Oh, you are joking."

"No, I 'm not; the men caught them and took them home to eat. You can ask them about it when you get up there. You see there must have been a direct connection with the river overhead. There was an unlimited supply of water, the whole Atlantic Ocean in fact, for that stream to draw upon, and it was impossible for the pumps to keep the tunnel dry. But patience and persistence finally resulted in a complete victory for the engineers. The tunnel was pushed through clear from Astoria to the Bronx."

"I wish," said Perry, "that we could have seen it while they were having the trouble. It won't be half so interesting to see a finished tunnel."

"But it is n't quite finished yet," said Mr. Barto. "The roof of the tunnel is concreted, but the bench or lower half is still to be excavated, so you will have a chance to see some of the seamy rock that has been bothering them."

"Then they might still have some leaks." suggested Perry, eagerly.

Mr. Barto laughed. "I am afraid you are destined to be disappointed. All their difficul-

ties, so far, have been in the rock overhead. Now that they have a good roof above them it is n't likely they will experience any further trouble. It looks to me as if the great campaign were all over but the shouting."

CHAPTER XVI

ROUTED BY A FLOOD

BECAUSE he was an old friend of the engineer directly in charge of the work, Mr. Barto had no difficulty in getting into the Astoria yards of the gas company.

"Capen," he said, "I want you to shake hands with a couple of my friends, Perry Carpenter and Jack Winans. We have come to congratulate you on your great victory and incidentally to look over the battlefield."

"Victory? Battlefield?" repeated Mr. Capen, mystified. "What are you talking about, Barto?"

"Oh, you modest man," laughed Mr. Barto. "You did n't know you were a great general conducting a long and most difficult campaign against an enemy with overwhelming forces at its command. As soon as I read the account of your struggle with floods 225 feet below sea level I told the story of it to these two boys, likening the work to a great battle or military campaign. It was a brave fight you put up,

Capen, and you deserved to be crowned with victory."

"Victory!" grunted Mr. Capen. "Come here and I will show you our 'victory'!" He led the way to the head works built over the shaft. "Look down there," he commanded.

"Why, Capen," exclaimed Mr. Barto. "It 's full of water."

"I should say it was," agreed Mr. Capen. "Yes, it 's a branch of the East River, that is what it is. Low tide now, but the water will be standing four or five feet higher by seven o'clock."

"But you don't mean to tell me that the tunnel is full of water," cried Mr. Barto.

"No, there is a little piece of the Bronx end that is still in our hands. All the rest we had to surrender to the enemy, just as that account of our work you read was going to the press."

"But how did it happen?"

Mr. Capen shook his head. "Have nothing to say except that we crowed too soon, but—Good Gracious—" he added, "who would n't do so. We had carved a hole all the way through from Astoria to the Bronx. We drilled test holes in every direction without striking water. The drift was widened to the full diameter of the tunnel, and we had exca-

vated most of the bench (the lower half of the tunnel). It was all done except for about 120 feet of bench when one of our test holes struck water under high pressure; then more test holes found water, and, to keep the lining of the tunnel from caving in a buttress of concrete 20 feet long was built against the side wall of the tunnel and heavily braced with timbers against the opposite side of the tunnel. For a week we let the water run freely through the drain pipes while the concrete hardened and then when we closed the valves in those pipes the water burst in through the bench and cracked that big buttress in two. I tell you it was disheartening to see all that water pouring in.''

''Did you catch any fish,'' asked Perry.

''Not that time,'' replied Mr. Capen, ''but plenty of material came in with the water, refuse of all kinds, tin cans, chunks of wood, and a whole lot of coal, showing there was a direct opening up to the river.''

''Where did the coal come from?''

''Why, there was a coal barge wrecked up here not long ago and I guess that accounts for the coal.

''We started at once to build a pair of safety bulkheads at each end of this trouble zone, with doors that could be dropped in case of emer-

gency to keep the finished sections of the tunnel from being flooded. We felt safer then and tackled that buttress again. The big concrete mass was carefully removed and a heavier and larger one was built in its place. This was 35 feet long and weighed 112 tons. It was very solidly braced against the opposite side, but when the flow of water was checked by turning the valves, would you believe it, that whole mass cracked open and moved away from the side of the tunnel, crushing the timbers that braced it. Of course this had to be removed, too, and everything was prepared for a still more solid buttress when suddenly the flow of water increased to such a volume that the men at work realized the emergency bulkheads would have to be used. So they closed the valves in the pipes through the bulkheads, slammed the safety doors shut and ran. But they were in such a hurry that they must have overlooked a valve on the Astoria side, because the water came running in there faster than we could pump it out. It was n't long before our pumps were drowned, and then there was nothing to do but watch the water rise in the shaft until it was up level with the river. Since then it has been rising and falling with the tide.

"I tell you it made us sick to see that water

take possession of the tunnel. The superintendent was for taking a boat down the shaft when the flood first occurred and rowing up to the bulkhead to close the valve. He is a nervy fellow, that Jim Doyle.''

''Jimmy Doyle,'' cried Jack. ''Is he here?''

''Why, do you know him?'' asked Mr. Capen.

''We all know him,'' cried Perry. ''Where is he?''

''Down at the Bronx bulkhead, I believe. We 'll go over there if you like and see how he is getting on with his job. Maybe you can get him to tell you about his experiences down there when the flood came.''

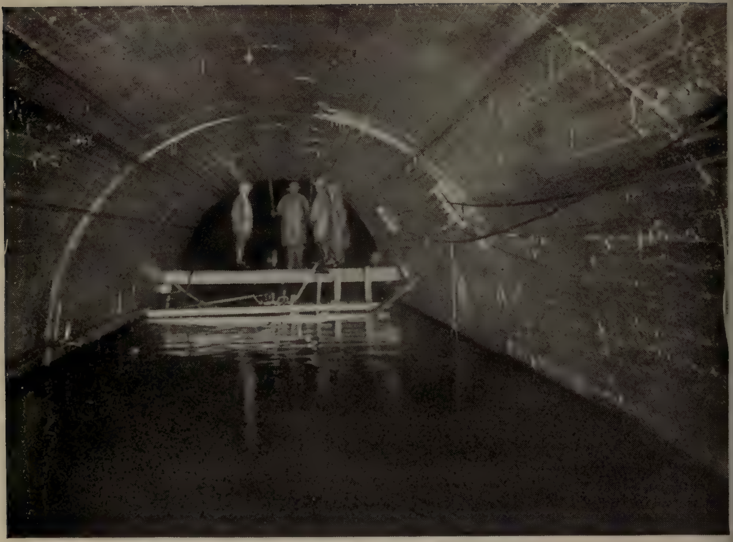
A launch took the party across the river. As they walked over to the shaft Jack saw a familiar figure.

''Why, there 's Jim Doyle now!'' he cried, running up to the man. ''Jim!'' he shouted. ''How are you?''

Jim turned abruptly. ''Well, if it ain't Jack Winans,'' he exclaimed. ''Where did ye drop from, and Perry, and Mr. Barto, too. Right glad I am to see ye all.''

''How long have you been here,'' demanded Jack.

''Oh, about a year,'' he said, ''and, believe me, we have had as purty a job as any I ever



NEAR THE ASTORIA SHAFT—THE TUNNEL PARTLY UNWATERED.

THE SURFACE OF THE "BENCH" IN THE TROUBLE ZONE COVERED WITH A THICK FLOOR OF CONCRETE AFTER THE TUNNEL HAD BEEN UNWATERED.

tackled. Water all the time, just pourin' through the rock like it was a sieve and we tried to make good rock by pluggin' it up with grout."

"Tell them about the flow that flooded the tunnel, Jim," said Mr. Capen.

"Shucks!" answered Jimmy Doyle; "there ain't much to say. If we 'd only been a little quicker we would n't be settin' around here with three quarters of a mile of good tunnel full of water. You see it was a Sunday morning about quarter to eight the water come pourin' in, bringin' a lot of rotten rock an' mud an' rubbish. It begin to look serious, then it slackened off and I had the men clean away the stuff around the bulkhead doors. Then about half past nine there come another big rush. I seen there was nothin' to do, but to hike out of there as fast as we could. Ye never see such streams of water as came pourin' in. Ye know the tunnel slants down to the Astory end, so when it 's finished any water that leaks in will drain off into a sump—that 's a well," he explained to Jack—"at the Astory shaft where it will be pumped out. So you see, naturally we wanted to close the Astory bulkhead first, because the water might run down and fill up the tunnel to the roof at the shaft and trap us in there like

rats, but there was so much sand an' mud come in with the water it was hard work clearin' it away to let the safety door drop. Be the time that was done an' the valves was closed it was gittin' purty deep in there outside the bulkhead, an' the men was gettin' so rattled they could n't do much. I could n't see what they was doin' on the other side o' the bulkhead, of course, but they must have forgot one o' the valves.''

''But do you mean to say, you stayed outside the bulkhead and cut yourself off from the tunnel,'' exclaimed Perry.

''Sure; I cut meself off from the Astory end, but not from the Bronx section. Ye see, I wanted to make sure the Bronx bulkhead was closed right, too.

''As I was sayin', be the time we got the Astory drop door closed the water was backin' up in there between the bulkheads purty deep. There was a 'mergency bulkhead on the bench near the Bronx bulkhead, but with a small doorway in it, and the water pushed me through that doorway faster than was dignified. Well, I got through the main Bronx bulkhead, all right, an' saw the men had all the valves closed good an' tight. Then I telephoned to the other end an' they said the water was pourin' into the Astory shaft faster than the pumps could handle it.

I knowed then that somebody had been too rattled to tend to business and had left a valve open in one of them drain pipes. I told 'em to get a boat down into the shaft at once so when I got over there I could row up to the bulkhead and see where the trouble was.

"But was n't it dangerous?" inquired Jack.

"Sure; there is danger in all this work. We don't stop to think about danger. But the water was pourin' in twicet as fast as the pumps could take it out. Those men are regular daredevils, but not one o' them would go with me, an' I seen there was no use tryin' to do anything. Well, there ain't no use talkin' about it now; the pumps was soon drowned out, but some o' them kept right on workin' under water till four o'clock in the afternoon. The water kep' risin' slowly an' it was n't 'til Monday night that it reached tide level. Ye see it takes some time to fill a hole three thousand six hundred feet long and eighteen feet acrost."

"And now how are you going to get the water out?" demanded Jack.

"Wished I knew," answered Jimmy Doyle.

"But you are doing something," persisted Perry.

"Yes," said Mr. Capen, "come on down and I will show you what we are trying to do."

They entered an elevator and were lowered far down into the rock. There they got out and walked along the dimly lighted tunnel. It did not look particularly exciting; just a great vaulted hall lined with concrete. After a short walk they came upon a group of men busily at work with a drill. Just ahead of them was the Bronx bulkhead. It gave Perry and Jack a creepy feeling to realize that behind this wall was an inexhaustible supply of water bearing on every inch of the surface with a pressure of ninety pounds. If that wall gave way they would be dashed to death.

"That bulkhead has to withstand hundreds of tons of pressure," said Mr. Capen; "the very first thing we did was to brace it with that buttress," pointing to a heavy wall of concrete that slanted against the middle of the bulkhead. "We tried, at first, to cut off the connection between the tunnel and the river by drilling holes at about the point where the flow occurred and then pumping in grout. We have given that up for the time being and now we are merely trying to close the leak in the Astoria bulkhead."

"But, how can you do that from here?"

"Why, simply by pumping in grout through a hole in this bulkhead. We are boring that

hole now. It is mighty lucky there is such a material as cement which can be mixed with water, and pumped like water; but which will turn into rock even when covered with water."

A hole had already been cut through the main bulkhead and now they were trying to bore through the emergency bulkhead beyond. When this was penetrated the drill rod, which was a two inch pipe, was to be pushed on through close to the Astoria bulkhead and then grout was to be deposited near the bulkhead door in the hope that it would pile up against it and close off the leak.

"If necessary," said Mr. Capen, "we 'll fill the whole space between the bulkheads with grout."

"I see the battle is n't over yet," said Mr. Barto, "but I 'll bank on you, Capen. You 'll win out in the end."

CHAPTER XVII

RETRIEVING A LOST TUNNEL

IT was fully a month later that the boys got back to the gas plant and hunted up Jimmy Doyle. He led them proudly to the Astoria Shaft.

"Last time ye was here, she was full up to tide level," he said. "She ain't so full now. Here, jump into this bucket and we 'll go down a ways."

The boys climbed into the bucket and, as they were swung over the yawning well, they looked down at the reflection from the still black water far below them.

"Why, you 've pumped it nearly all out," cried Jack.

"Well, no, not exactly. There 's still enough to drownd ye several times over," answered Jimmy Doyle.

When they reached the bottom they climbed out upon a pontoon that carried two of the pumps.

"Your pumps are not working to-day, are they?" remarked Perry.

"No, we had to stop yesterday because the water was going down too fast. We 're afraid to pump any more."

"Too fast? Why, what do you mean?"

"We were pumping out the shaft and not the tunnel," answered Jimmy Doyle. "Ye know the tunnel dips so it 's twenty feet higher at the heading than it is at the shaft. As long as no air can get in there to take its place the water just stays up in the tunnel well above the level here in the shaft."

"You mean there is a vacuum in there?" asked Perry.

"Yes, the air pressin' on the water here in the shaft is holdin' back the water in the tunnel."

"But what of it," asked Jack. "Can't you keep on pumping out the shaft just the same?"

"What of it," echoed Jimmy; "of course we can keep on pumpin' the shaft, but when we get low enough for the head of the water to be greater than the air pressure in the shaft, then there will be a rush of water as will wreck the whole place. No sirree; I would n't care to be down here when all that water broke loose."

"There is n't any danger of it now, is there?" asked Perry, apprehensively.

"Well they figger there is about a million gallons of water held back up there ready to swamp us if it gets a chance."

"But are you sure there is no air in there?" insisted Jack. "It seems to me a lot of air must have been trapped in the tunnel when it first filled up."

"Right ye are," agreed Jim, "but it all bubbled out into the river, and there ain't no more in there."

"Well, how are you going to put the air in there then?" asked Perry.

Jimmy scratched his head. "I don't know," he said, "I 've been trying to figger it out. We tried boring through the Bronx bulkhead, but we could n't seem to make much headway. Anyway, 't ain't up to me to figger it out, that 's the boss's job."

When they reached the surface again, Mr. Capen was looking for the superintendent. "I 've got a scheme, Jim," he announced. "We have an air line in the tunnel. Suppose you turn on the pressure and see if you can't blow some air in."

"But, Mr. Capen," protested Jimmy Doyle,

"the valves is shut, as they should be, an' ye can't put any air through. In fact I tried it meself, this morning."

"You did, hey!" Mr. Capen's jaws came together with a snap. "Well, try it again," he commanded. "Throw on all the pressure you can get. We 'll blow off the end of the pipe, if necessary."

"All right, sir," replied Jimmy.

The boys went with him to the power plant and watched him direct the starting of the big compressors. Then they noted the pressure gage as the air pressure was put into the pipes. They saw the pointer move jerkily from 50 lbs., past the 100 mark, past 150, up to 165; then suddenly drop to 35 lbs.

"Hurray," cried Perry; "must be a blowout somewhere."

Jimmy scratched his head perplexedly. "At 165 lbs.? Never. But what could it be? Must be that valve was open after all. It may be—yes, it was that chump Mike Callahan. Wait till I get him!" he cried.

"Why, what is the matter?" asked Jack.

"That valve was never shut," declared Jimmy Doyle. "Must be there was mud or rubbish clogged in the pipe or she would n't have

blown at 165 lbs. I told Callahan to shut the valve meself, an' he told he he done so. He 'll catch it for lyin' to me like that."

"Well," broke in Mr. Capen, who had just come up, "I don't know as I 'd be so hard on Callahan. It pays to have an incompetent around sometimes. Callahan has certainly done us a good turn this time. Now, if nothing happens, we 'll take a boat ride in the tunnel to-morrow or the next day and see how things look."

The boys were fully as excited over the prospect as if they themselves had been building the tunnel.

"Wish we could go down with you," said Jack, after Mr. Capen had gone.

Jimmy Doyle eyed them narrowly, then he winked at Jack. "Tell ye what I 'll do," he whispered; "Jack, I know you for the work we 've done together. Have ye got the nerve to go in there with me as soon as the tunnel portal is uncovered?"

"Surely," answered Jack.

"Well, you get around here to-morrow night. I figger she 'll be down low enough for us to get in then, and we 'll take a boat ride of our own before the boss gets here. But not a word now to anybody."

"How about me?" cried Perry. "Don't I come in on this?"

"If you 've got the nerve, ye can come along too," replied Jimmy Doyle.

The next night furnished all the excitement a boy could wish. The adventure itself promised thrills enough, but what made it doubly exciting was that they were going to engage in an expedition that would surely be forbidden if Mr. Capen knew of it.

"It 's agin the rules, I know," said Jimmy Doyle, "but I 'm lettin' you in for old time's sake."

It was about two o'clock in the morning when Jimmy Doyle smuggled them into the plant.

"I 've got a boat down there all ready," he said, "and a couple of electric flash lamps, but we 'll have to wait some more. The water ain't down fur enough yet. Ye might as well get some more sleep," pointing to a cot. "She 's going down about ten inches an hour, and the top of the portal is only just uncovered. In about three hours it 'll be ready for our trip."

He lay down on a bench in the engine house, covered himself with a heavy coat and was soon fast asleep. As for Jack and Perry, they were far too excited for slumber. They tossed around sleeplessly for an hour or more on their

uncomfortable cot. Then it seemed as if they had only just fallen asleep when Jimmy roused them.

"Come," he said, "if ye 're goin' with me."

Not more than half awake, they staggered after him and climbed into the bucket that was to lower them into the shaft. At the bottom of the shaft they crawled out into a boat. It was pitch black, except for the two spots of light cast by the electric lanterns on the walls of the deep well.

"Which way is the tunnel?" asked Jack, who had completely lost his bearings during the descent in the swinging bucket.

Jimmy Doyle swept the light around the water's edge. "There," he said, directing the rays upon a wide, but very low opening in the side of the shaft. "Not much head room, but I guess we can squeeze through."

"But how are we going to row the boat?" asked Perry.

"Leave that to me. We don't need to row until we have more head room. There 'll be plenty of head room farther on. Why, we 'll ground the boat long before we reach the headin'. Now you lie as low as you can."

Perry had no idea how Jack felt, but he had

to struggle valiantly against the dread that gripped him. They were going through the neck of a bottle. If anything happened, they would be trapped like rats.

Obedient to Jimmy Doyle's order the two boys dropped to the bottom of the boat while Jimmy Doyle, also crouching low, propelled the craft up the tunnel by pushing against the roof with his hands. They proceeded thus about 100 feet when there was a crash. Both Jack and Perry uttered a cry before they could master their tense nerves.

"Just a timber we 've run into," Jimmy Doyle reassured them. "Did n't suppose there 'd be any as near the portal as this. But say, I 'm a big fool to take you young fellers in here. This is no boys' play. I 'll take ye back and go it alone."

However, Perry and Jack were heartily ashamed of themselves by this time for their involuntary cry and insisted on accompanying him the rest of the way. Already they noticed a decided increase in head room. Jimmy Doyle very wisely set the boys to work at the oars so as to keep them busy, while he played the lamp upon the water ahead, keeping a sharp watch for snags. It was not long before they could sit upright, while Jimmy Doyle directed them

to pull stronger to port or starboard to avoid this or that obstacle. The wreckage had been piled high in places.

"Look there," cried Jimmy Doyle. Right ahead of them a couple of steel cars had been tossed one on top of the other as if they had been sticks of wood. "It shows you there was some brook flowing through here, a regular spring flood," he declared. "What gets me is where it all come from. I shut the bulkhead door meself, and how all this water could come from a eight inch drain pipe is more than I can figger.

"Here 's the end of our voyage," cried Jim, presently. Ahead of them was such a pile of junk, timbers, cars, tools, and what not, that they could not possibly navigate their boat through it. However, the water was shallow now and as they had been furnished with hip boots, they jumped out, climbed over the wreckage and then waded on toward the bulkhead.

Presently they waded out of the water into a soft, white mud. Jimmy Doyle stopped to examine it.

"Grout," he exclaimed. "It must have leaked through the bulkhead somewhere, and it was too thin to harden."

A bank of grout which gradually grew harder

extended all the way up to the bulkhead door, and this they found ajar.

Jimmy Doyle stopped and scratched his head again. "So that was it," he muttered. "Something must have caught under the door. I thought I shut it tight meself, an' here I 've been blamin' the men for leaving the drain pipe open."

The bank of grout was so deep as to cover the drain pipe completely, but the end of this pipe ran out into another larger pipe which led far back into the tunnel. It was good for their peace of mind that the party did not know the precarious condition of that pipe. They did not realize that their lives depended upon a few chips of wood, an old rag or two and other bits of refuse. It was several days later that the grout was dug away enough to expose the valve of the drain pipe and as soon as that was touched the rubbish that choked it blew out. Immediately a heavy stream burst into the tunnel, but it was soon checked by closing the valve. Had this rubbish blown out, now, when the two boys and Jimmy Doyle were in the tunnel, with no chance of reaching the valve, very probably the tunnel would have filled sufficiently to cut off their escape long before the boat could have been rowed to the portal.

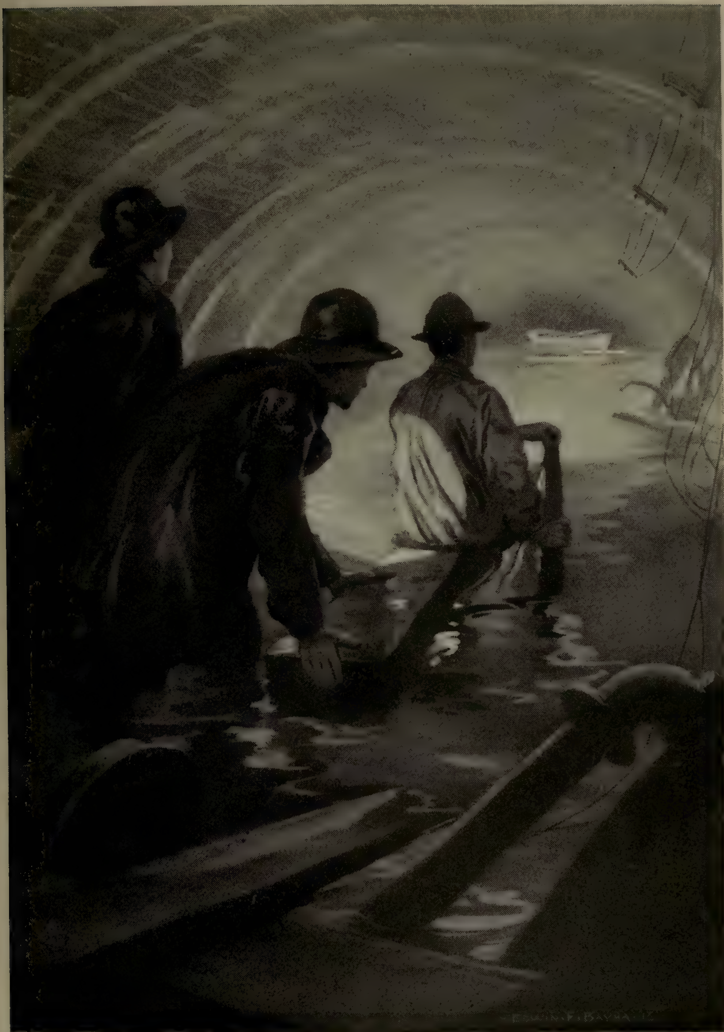
The excavation of the bank of grout also cleared another puzzle. Jammed under the bulkhead door was a mere chip of wood an inch thick and four inches long. That was what had held the door ajar. That little block of wood was responsible for tying up the tunnel these many weeks, and it was through the crack in the doorway that the grout, which had been pumped in from the Bronx bulkhead, had poured out into the tunnel, banking up to a depth of twelve feet before it had mounted high enough to choke off the leak.

Overhead there was a three-inch cableway pipe through which water was gushing in a goodly stream. But of course there was no valve on it and no way of stopping the flow.

They spent some time down there at the bulkhead studying conditions as well as they could with their meager light. Then they started back.

"Pumps are doin' their duty," announced Jimmy Doyle. "No danger of bein' trapped this time." He pointed to a mark he had made at water level when they came in. The mark was now at least four inches above the water.

They splashed back to the jam of wreckage where they had left their boat. Perry was



JIMMY DOYLE STARTED OFF IN PURSUIT OF THE DRIFTING BOAT.

ahead with one of the lanterns. Suddenly he gave a cry.

"Where 's the boat?" he shouted. "The boat 's gone."

"What 's that you say?" asked Jimmy Doyle, running forward.

"Is n't this where you left the boat? Well, she 's gone."

"Huh!" grunted Jimmy Doyle, scratching his head. "That 's where I left her all right, with her nose caught under that timber."

"There she is, way off there," cried Perry, focusing his lamp on an object about three hundred yards off.

"Drifted away, by George!" exclaimed Jimmy Doyle.

"Who 'd have thought she 'd drift away," remarked Jack, "with no wind, no waves, and no tide."

"Hold on, there *is* a tide, ain't there? An' she 's goin' out fast," said Jimmy Doyle. "Dropped four inches while we was up to the heading. Two inches was enough to set her free, an' then what with the water pourin' in through the three-inch pipe an' the pumps drawing the water out of the shaft, there must have been enough current to carry her off. Well, I must say, it 's the first time I ever left a boat

without tyin' her. I 'd fire any other man for bein' so careless."

"But what are we going to do?" cried Perry. "How are we going to get out of here?"

"We might swim for it," suggested Jimmy Doyle. The idea of swimming in that dark hole did not appeal to the boys in the least.

"I s'pose we might wade as far as that," said Jack. "It can't be much more than waist deep there."

"Sure," answered Jimmy Doyle, "but what 's the use of gettin' wet? Give me a hand with this timber, an' I 'll show ye how to get the boat."

The boys helped him haul out a big 12 x 12 inch beam. Then sitting astride the beam, the lantern perched in front of him, and a short slab of wood for his paddle, Jimmy Doyle started off in pursuit of the drifting boat.

The boys watched him propel his unwieldy craft up the black tunnel. To them it seemed an endless time before he captured the runaway boat and came rowing back to them.

The trip out of the tunnel was rather prosaic, until they neared the portal. To be sure they had more head room than before, but somehow it seemed more alarming to be rowing into a constantly shriveling space, even though it did

lead toward the portal, than it had before to be traveling toward the heading. The arch above seemed to be closing down upon them as if it would crush them and bear them down into the black water. Just as the sensation was growing almost unbearable, they shot out of the tunnel into the open shaft. Many a night after that did Perry, in his dreams, go through exaggerated reproductions of this experience.

Months elapsed before the tunnel was finally completed. Trouble with water had not ceased entirely. Bad leaks were encountered, but much had been learned as to the best way of meeting the difficulties and never again were the engineers obliged to give ground to the river.

CHAPTER XVIII

LAYING A BLANKET ON A RIVERBED

"DO you know," said Jack, as they left the gas plant, "night school begins week after next, then we 'll be tied to the desk night and day. I think we can do better at school if we have a change of work, don't you?"

"What kind of work?" asked Perry.

"Suppose we try to get something to do on the new subway. We 'll learn more engineering in a week than we could in a month in the office."

"Great idea, Jack," cried Perry. "Let 's see if we can't locate a job on one of the East River tunnels. I believe there is more excitement in tunnel work than in anything else."

It was too much to expect that both boys would find work together. However, both of them did locate jobs in the subway tunnels, Perry as a timekeeper on one of the sections running under the river and Jack, despite his limited experience, as a rodman on the part

running inland from the river on the Brooklyn side. In both sections compressed air had to be used to keep out the water. The work was new to the boys, but they found it very much like sinking a shaft with a pneumatic caisson, except that the shaft was horizontal instead of vertical. They had to go through an airlock to get into the part of the tunnel that was under pressure. The tunnel itself was a tube of cast-iron plates heavily ribbed and bolted together. At the forward end of this tube was the shield which took the place of the caisson. But here was where they found the principal difference between sinking a shaft and driving a tunnel. When sinking a shaft the whole lining of the shaft moves down with the caisson and the new rings of lining are added on top. But in a tunnel it is out of the question to move the lining forward, so, instead, the shield is pushed forward and the new sections of lining are added at the shield.

Now both Jack and Perry had supposed the tunnel shield to be some sort of an excavating machine. They were surprised to find that it is merely a huge cap fitting over the end of the tube. There were sliding doors in the cap through which the workmen could pass out in front and excavate the material ahead, to let the

shield be pushed forward. The shield was moved by means of hydraulic jacks, but it was not pushed far enough to uncover the end of the

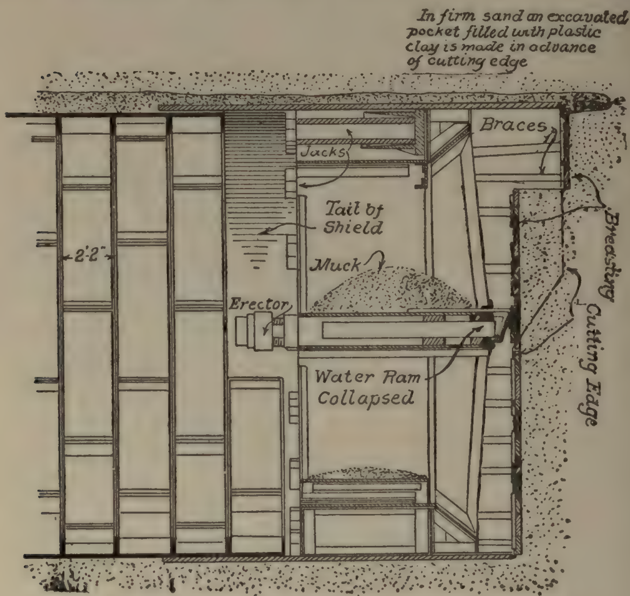


FIG. 21. DIGGING IN FRONT OF THE SHIELD.

tube and the new ring of lining was added within the shelter of the "tail" of the shield.

Out in front of the shield was what corresponded to the working chamber of the caisson. The shield extended forward into a cutting edge which would make a clean round cut as the

shield was pushed ahead. Overhead there was an extension called an "apron" which protected the workmen from a sudden cave in. The silt that was dug out by the laborers was shoveled

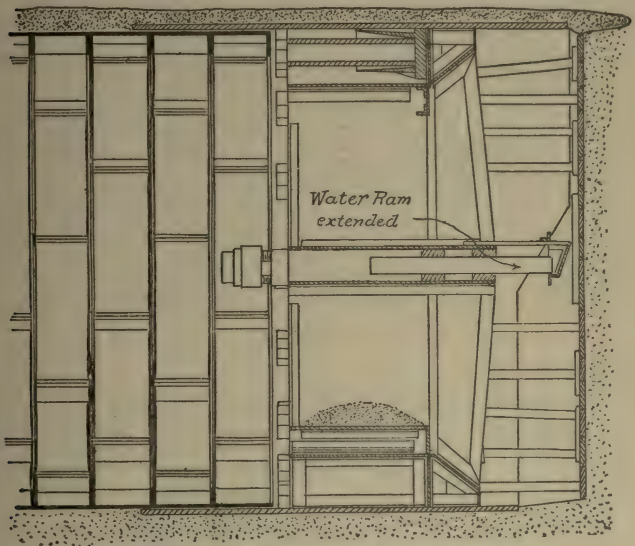


FIG. 22. READY TO SHOVE THE SHIELD.

through the doors in the diaphragm of the shield and unloaded into muck cars and hauled away.

In Perry's section special precautions were taken to prevent the silt from caving in on the men. A timber wall or "breasting" was built across the face of the heading within the shelter

of the shield. The breasting was advanced section by section and then the shield was pushed forward. Figures 21 to 23 illustrate the different steps in the progress of the work.

At the end of the first day of work both boys

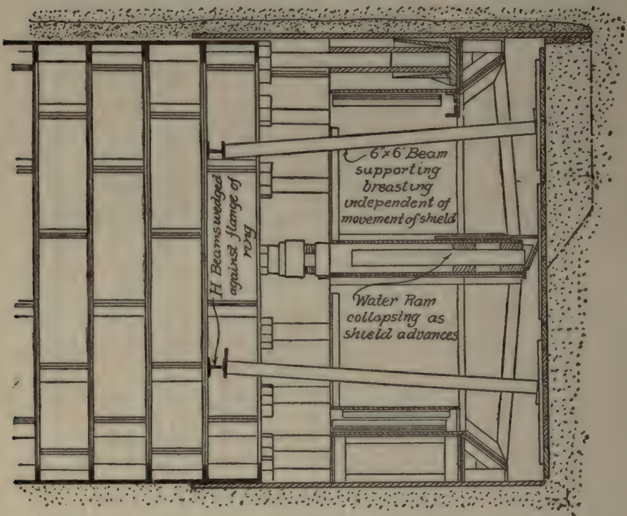


FIG. 23. AFTER THE SHIELD HAS BEEN ADVANCED.

came back delighted with what they had seen and done. Jack started to tell Perry all about the tunneling shield and was plainly disappointed when he learned that Perry knew as much as he did about it.

Perry had brought along a blueprint that

A DIVER AT WORK IN A FLOODED TUNNEL.

AVALANCHE OF MUD AT THE SHIELD FOLLOWING A BLOW-OUT.

gave a profile of the course of his tunnel. He laid it out on the table and pointed to the spot where they were at work.

"Pretty tough job right there," he said. "We are running along a buried ledge. The

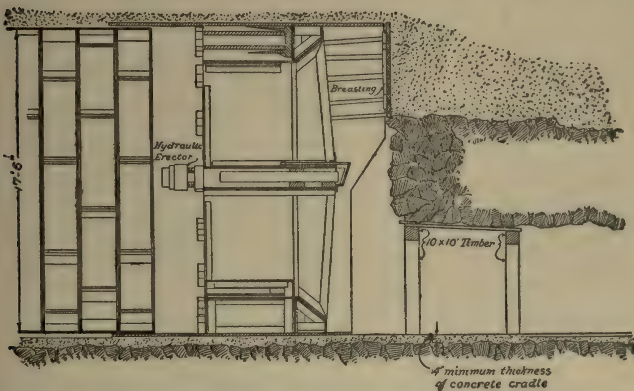


FIG. 24. HOW THE TUNNEL IS EXCAVATED WHEN ITS FLOOR IS IN ROCK AND ITS ROOF IN SAND.

floor of the tunnel is in rock and the roof in quicksand."

"How in the world can you run a shield through such a combination?" asked Jack.

"Say, you must have the same notion of a shield that I had. I used to think that the shield did the digging, but I found to-day that the men do all the digging in front of the shield."

"Oh, yes," said Jack. "I know that, but how do they blast the rock without blowing up the bed of the river too?"

"Well, you see," explained Perry, "they dig out over the rock as far as they dare go under the apron of the shield. Then they build a timber bulkhead from the top of the rock up to the apron. After that they tackle the ledge of

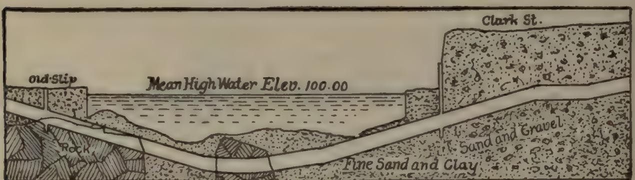


FIG. 25. PROFILE OLD-SLIP—CLARK ST. TUNNEL.

rock with light blasts of dynamite. Of course the doors in the diaphragm of the shield are closed during the shooting so that there is no danger of flooding the tunnel." (See Figure 24.)

Jack was studying the profile map closely. "Look here, Perry, what does this mean?" he demanded. "There seems to be mighty little cover over your tunnel in some places, but over here near the Brooklyn shore it actually breaks out through the river-bed. It seems to me it is bad enough to have the floor of your tunnel in rock and your roof in quicksand, but how in the

world are you going to make out when your floor is in quicksand and your roof in open water?"

"Oh, I found out all about that this noon. One of the men explained it to me. They laid a blanket on the riverbed all along the line of the tunnel."

"A blanket? What do you mean?"

"Well," replied Perry, "this is the way it was explained to me. When they drove the first subway tunnel under the East River, they had a lot of trouble with the air leaks because the quicksand and soft mud of the riverbed made a very poor cover. Why, one time, there was such a big blowout that it shot a man out of the tunnel right through the mud and up to the surface of the river, and he was picked up by a boat uninjured."

"Oh, yes," interrupted Jack, "I heard about that, way out at Thunder River."

"Well," Perry resumed, "the engineers on this job decided that they were not going to have any such trouble this time. They figured that it would pay them to make an artificial riverbed of clay under which the work could be carried on in perfect safety. So along each side of the line of the tunnel, they dumped rock to make a pair of parallel walls. Between

these walls they dumped bargeload after bargeload of clay. In some places that clay blanket is fifteen feet deep. You 'll notice that the river is very deep near the Brooklyn shore. It seems that the tide sweeps around there scouring out the bottom. The current is so strong there that they were afraid it would wash the clay blanket away. That 's why they built the stone wall on each side. Then, to hold the clay down, they piled more rock on top of it. You see, that makes a pretty good covering for the tunnel, because water can't run through clay. We ought to have a fairly dry tunnel and we expect that as soon as we get past this reef the work will go along humming."

"By the way, speaking of an artificial riverbed," said Jack, "they tell me they tried using grout down in our tunnel, something as they did in the Astoria tunnel. First they sank a big steel caisson large enough to take in both tunnel tubes side by side. In this caisson were portals for the tubes, but they were closed, of course, with steel plates, while the caisson was being lowered, and then the plates had to be taken out to let the tunnel shields through. This is usually a ticklish job for fear a flood of water and silt, or sand, will come in and swamp everything. But this time some one hit

upon the plan of building a tube of cement out in front of the caisson before opening the portal. A ring of holes was provided around the portal, through which pipes could be driven into the sand outside for a distance of thirty or forty feet. Then the idea was to force grout through the pipes and at the same time withdraw them."

"I see," cried Perry, delighted; "great scheme! They 'd have poles of grout forty feet long sticking into the sand and I suppose the grout would spread enough between the poles to make the ground pretty hard."

"Yes," answered Jack, "that was the idea, but it did n't work. There was nothing but very fine sand around the caisson and it is pretty hard to drive grout through sand."

"I don't see why it should be."

"Well, fine sand makes a good filter, you know, and what it did was to filter all the cement out of the water, leaving nothing but pure water. They could n't get enough cement into the sand to do any good."

"That 's funny, is n't it?" remarked Perry. "I never would have thought of it."

"But I tell you what we are doing with grout," said Jack. "You know when the first subway was run up Joralemon Street in Brook-

lyn, the course of the shield could be followed like the burrow of a giant mole by the settlement of the street and the racking of the buildings along the line. You know the shield fits like a cap over the end of the tunnel lining and naturally must be larger in diameter, so the tunnel lining makes a loose fit in the hole cut by the shield. Now you 'd never suppose that would make the slightest difference, way down there fifty feet below the level of the street. But it does. First the ground directly over the tunnel starts to cave in, then the ground just above that falls in, and so a settling starts up that goes on until it is felt all the way up to the surface."

"That shows how solid this old earth of ours is," commented Perry. "It 's hard to believe that there are no gaps in the ground anywhere."

"Yes," continued Jack, "it may take a day or two, but in time the track of the big mole will show in the street overhead. But you can't see a trace of our tracks, because our shields are fixed so as to fill up the space around the tunnel. In the tail of the shield there are holes through which gravel is shot back around the tunnel lining. Then grout is also forced in behind the tunnel plates, leaving

the ground in the wake of the shield just as solid as it ever was."

It was less than a week after this that Perry came in late one evening, greatly excited.

"Have you read about it?" he gasped.

"About what?" queried Jack.

"Don't you hear them crying 'extras'? We 've had a terrible accident in the tunnel, a big blowout; three men blown clear through the riverbed. I was in it myself."

"What?" cried Jack. "Do you mean to say that you were blown up into the river?"

"No, but the blast blew me right out through the door of the shield. I saw three men disappear through the mud, and I and two others caught hold of the apron or we 'd have gone too. I had to hold on for all I was worth."

"Did you get hurt?"

"No, it was all over in a moment. A great bubble of air puffed out of the tunnel. That reduced the pressure and then the water started to pour in. We got back through the diaphragm of the shield all right, and ran out ahead of the mud and water to the air-lock."

Jack surveyed his chum enviously. "By George!" he exclaimed, "I wish I'd been there."

"It was a great experience," said Perry. "I never thought, when I read about that fellow who was shot through the first subway tunnel, that I should come so near doing the same thing myself."

"But, Perry," said Jack, "I don't see why you had that blowout. I thought your tunnel was covered over with clay?"

"So it is," answered Perry. "I asked one of the men about it, and he said there might have been a low spot in the clay there. They figure it this way,—there must be enough air pressure in the tunnel to balance the water pressure outside. But the pressure of the water in the ground is greater at the bottom of the shield than it is at the top, where the water is not so deep. If the air pressure in the tunnel were heavy enough to balance the water pressure at the floor of the tunnel, the air would bubble out at the roof. That 's why we have to have a solid cover overhead—just to take care of this excess air pressure. If the depth of clay is not enough to hold down the air, there is going to be a blowout. We were supposed to have twenty feet of cover overhead, to-day, but you see, when they dumped the clay in, they could not tell whether they were getting an even depth all over. There must be some low spots

here and there, and I suppose this was a low spot where there was not weight enough of clay to hold down the air. At any rate, it was a blowout, all right, and it all came so suddenly and was over so soon that I scarcely realized anything had happened."

CHAPTER XIX

AIR AS A JAILER

JACK Winans found his work in the night school very interesting. The only trouble was that he had little time to study, and then, too, his hours at the tunnel were very irregular. Frequently he was kept late for some special work, particularly as he was used as a sort of a handy man for a great variety of jobs. This rather pleased him, although on more than one occasion, he had been obliged to hurry off to school without even a bite of supper, for it gave him a wider experience than he could have obtained if he had been confined to one line of work.

It was getting late, one day, when Jack was sent with a message to a man in one of the tunnel sections. He had to go through an airlock to reach him. Much to his annoyance, he found that a carload of sand had been derailed right in the doorway of the airlock and there was no chance of getting through until the wreck was cleared out of the way.

But Jack knew another, though longer, route. He would go through the northbound tube. There was a cross-drift connecting the two tubes about two hundred yards from the locks. He would go up through the northbound tube, cross over to the southbound tube, and come back to the point where he was to deliver the message.

In the bulkhead across the northbound tube, there were two locks, one large one for cars of spoil, and the other, a small one, not more than three feet in diameter, for men to go through. No work was being done on the northbound tube and the locks had not been used for some time. When Jack crept into the lock, with a candle for a light, he found the floor of the lock covered with old rope, pieces of pipe, and a varied collection of junk. However, there was plenty of room for him to crawl through. So he slammed the door shut behind him and turned the outlet valve.

The handle of the valve was merely a socket wrench, and he had to take it with him to open the inlet valve at the other end, which would admit compressed air into the chamber. He crept over to the other end of the tube, fitted the handle to the stem of the valve, and turned it. There was a hiss of air rushing in and, in the

same instant, he was plunged in darkness. The blast of air had blown out the candle. Jack fumbled nervously in his pocket for a match, but not one could he find.

"This is a fine pickle," he muttered to himself, "but I might just as well go on."

Although that section of the tube was very sparsely lighted, he could easily grope his way along, so he kept on opening the air valve. But strange to say, it took an endlessly long time for the lock to fill. Finally he realized that there must be a leak somewhere. It occurred to him that maybe he had failed to close the outlet valve completely.

He started back for that end of the lock, when, as luck would have it, his foot caught in a tangle of rope and pitched him down on his face. In his excitement, he dropped the valve handle. Now thoroughly alarmed, Jack felt all around for the wrench, but he could n't find it. Several times he thought he had it, but each time his find proved to be a piece of junk. The longer he looked, the more frantic he became. He tore away at that junk pile in desperation, but it was like looking for a needle in a haystack. Finally, he had to give up the search, but he was in a frenzy now. He scrambled over to the outlet door and began tugging at it with all his

might. There was no visible latch to fasten the door, but the air pressure in the chamber was heavy enough to hold the door shut despite his utmost efforts. Back he struggled to the other end of the lock and flung himself at the door there, but that would not yield either. The air pressure in the tunnel on the other side was sufficiently greater than that in the lock to hold him prisoner.

Thoroughly exhausted, Jack sat down there in the dark and pondered over his predicament. What could he do? This was a little used part of the tunnel. There was little likelihood that any one would come across him there, for days. No danger of his smothering there, with all that air pouring through the lock, but would n't he starve to death? He must find that valve handle. He must keep on hunting for it—a hopeless search, maybe, but it was better to be doing something than to sit there cooped up in that narrow black chamber brooding over his fate. So he started a thorough and methodical exploration of that litter of junk.

Two hours elapsed before the superintendent learned that his message had not been delivered.

"Funny," he said. "Jack is such a reliable fellow, I believe something must have happened to him."

A search was instituted. High and low they looked for him. Finally the superintendent bethought himself of the northbound tube. He had no idea of what Jack would be doing in that part of the tunnel, but he meant to make a thorough search.

As the superintendent neared the bulkhead, a violent hammering attracted his attention to the airlock. He noticed the hissing outlet valve and immediately closed the pipe. Then he locked himself through to the other side of the bulkhead by way of the large airlock. But before he had reached the other side, enough air had accumulated in Jack's prison to equalize the pressure on both sides of the inlet door. The door had yielded to Jack's push and he had escaped from his dungeon. But he was so used up by that time, that he could barely walk.

"Well, Jack," remarked the superintendent, when he had heard the whole story, "you 've had a trying experience, but it has taught you the danger of carelessness, I guess."

"Indeed it has," answered Jack.

CHAPTER XX

FARMER BILLUPS

"MR EBENEZER BILLUPS and his wife to see you," announced the office boy.

"Billups? Billups?" puzzled Mr. Barto. "I don't recall any one of that name. But show them in."

Presently a powerfully built man strode into the room, followed by a rather timid old lady.

"Howdy, Mr. Barto," he cried, extending a horny fist. "Guess you 've forgotten me and Judy, as had the farm out at Thunder River."

"Well, well!" exclaimed Mr. Barto. "Aunt Judy and Farmer Billups. Oh, no, I have n't forgotten you. It 's mighty good to see you again. Sit down, won't you, and tell me all about Thunder River. By the way, how 's the dam holding out?"

"Say, I 've got to hand it to you, Mr. Barto!" exclaimed Mr. Billups. "You made a good job of that dam, and I told 'em all you could never do it. She 's holding all right. Why, last spring we had the biggest freshet I ever seen.

The dam up at Blaney's went out, but your dam stood up as solid as a rock."

"Of course it did," said Mr. Barto. "I don't take any credit for that. All we did was to dig down far enough to anchor the foundations to bed rock. The only reason the first dam failed was because the engineer did n't have money enough to put good foundations under it.

"But tell me, what brings you here so far from home?"

"Well, crops have been fine since they got that irrigation scheme finished, and me and Judy, we thought we 'd take a trip back to Vermont, where we both come from twenty year ago, and see some of the old folks again. Judy, she was plumb bent on coming to New York to see you about that good-for-nothing Jack we used to have on the farm."

"Oh, Ebbie," interposed Mrs. Billups, "he was n't good for nothing. He was a fine, manly fellow, only you were too hard on him."

"There you are," cried Mr. Billups; "women are so soft. That 's the way she goes on whenever I say anything about the boy. To think we took him out of an orphan asylum and fed him up and clothed him and sent him to school and then the rascal runs away!"

"But, Ebbie," protested Mrs. Billups, "you know you did n't—"

"Yes, I did, too," retorted Mr. Billups. "I treated him fair enough. It 's no use to quarrel here, Judy. I say he was no good. He was n't square, and I was glad to be rid of him. But I give in to you and let you come here to bother Mr. Barto. Now I hope you 're satisfied.

"They say," turning to Mr. Barto, "as how the boy come to you here, and Judy wants to know, can you tell her where he is now."

"He 's in Brooklyn," replied Mr. Barto.

"In Brooklyn!" exclaimed Mrs. Billups, delighted. "Ebbie, we 'll go right over and see him."

"I 'm sorry to say you can't see him now," said Mr. Barto, looking at his watch; "he 's under ground."

"Dead and buried?" shrieked Mrs. Billups.

"No, no," Mr. Barto hastened to reassure her. "He 's very much alive. He 's working on one of the subway tunnels over there and you would n't have a chance to see him before six o'clock. In the evening he goes to night school."

"There, what do you think of that, Ebbie?" said Mrs. Billups, triumphantly. "A no-ac-

count boy would n't be spending his evenings at school. I told you he would amount to something."

"You 're right, Mrs. Billups," spoke up Mr. Barto. "That boy has the right stuff in him. He 's the most independent fellow I ever came across and won't let me help him a bit. Even his chum, Perry, whose father has lots of money, can't do a thing for him. He 's doing fine work in the tunnel and stands high in his studies. When he gets through school, there 's a good position awaiting him right in this office. The men he works for think a lot of him. In fact, he 's quite a hero, since he saved the lives of half a dozen of them a couple of months ago."

Mrs. Billups' face was fairly beaming, and she kept nodding her head triumphantly at her husband, who seemed somewhat uncomfortable.

"They were sinking a shaft for the ventilation of the subway," Mr. Barto went on. "The caisson was down quite a ways."

Here Mr. Barto had to stop and explain to Mrs. Billups the nature of a caisson. It is not probable that she obtained a very clear mental picture of the situation, but she had a vague idea of a group of men in a big box far under

ground who were kept from being drowned out by means of air pumped down to them.

"It seems the pumping plant was insufficient for the work," Mr. Barto went on. "They had great difficulty in getting more than four pounds pressure down there. The shaft was located down at the bottom of a hill. About two months ago, we had a terrible rainstorm. It was a regular cloudburst. The streets were flooded. The storm sewer on the next street above the subway shaft burst, and the water came pouring down the hill and into the shaft."

"Right on the men?" asked Mrs. Billups, greatly excited.

"Oh, no; they were in the caisson, you know. Jack had just come up from below when he saw the torrent pouring down the hill and he knew instantly what it meant. If the water filled the shaft above the level of the airlock, the men would be trapped below until pumps could be installed and the water pumped out. But worse still, the doors in the airlock were held shut merely by the air pressure inside, and that was only four pounds to the square inch. It would take a depth of but eight feet of water over the airlock to force those doors open. Then what would happen to the men! There was n't a moment to spare. They must be got

out of there at once. Ordinarily there is a telephone to the working chamber of a caisson, but there did not happen to be any at this shaft, and there was no way of telling the men below what danger they were in. All he could do was to signal to them to come out.

"It 's taking me some time to tell you all this," continued Mr. Barto, "but Jack did not stop a minute. He just jumped into that airlock and carried the message down to the men himself. It was a small airlock, not more than two at a time could go through. Jack stayed down there until he had hustled every one out. He was the last one to come through, and by that time the water stood six inches above the top of the airlock. The men could n't have gotten him out if they had n't built a dam around the top door of the airlock with bags of cement. Now that showed real nerve, I say. You 'll not blame me for being proud of the boy."

Aunt Judy got up and shook her finger in the big man's face. She was trembling with excitement. "Ebenezer Billups, what have ye got to say?" she demanded.

Farmer Billups was evidently having a struggle with his obstinate self. He shifted uneasily.

"Mr. Barto," he said, "where did ye say

Jack is working? Don't care if I can't see him now, I 'll hang around till he comes out.''

''Oh, Ebbie,'' cried Aunt Judy with delight.

''Now, Judy,'' said Mr. Billups, ''that tunnel ain't no place for women folks to be hanging round. I 'll take ye back to the hotel, and then I 'll go and fetch Jack.''

''I can get a message to him by telephone,'' suggested Mr. Barto.

''No, thank ye, I 'd ruther see him myself first.'' And Farmer Billups strode out of the room with little Aunt Judy keeping up a lively chatter at his heels.

Late in the afternoon, Mr. Barto's telephone bell rang. It was Jack.

''Hello, Mr. Barto. You remember Farmer Billups, don't you? He 's in town with Aunt Judy, at Hotel ——. We 're going to have a sort of family reunion there, to-night, and he wants you and Perry to join us at dinner. Can you come?''

''Sure, you can count on me,'' answered Mr. Barto.

THE END